J. C. Brannan

PROCEEDINGS

OF THE

Liverpool Geological Society.

SESSION THE THIRTY-FOURTH,

1892-93.

Edited by H. C. BEASLEY.

(The Authors, having revised their own Papers, are alone responsible for the facts and opinions expressed in them).

PART 1. VOL. VII.

LIVERPOOL:
C. TINLING AND CO., PRINTERS, VICTORIA STREET.
1893.

St

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LIST OF SOCIETIES, ETC., TO WHICH THE PROCEEDINGS OF THE LIVERPOOL GEOLOGICAL SOCIETY ARE SENT.

*(Publications have been received in exchange during the Session from those marked *).*

*Academy of Natural Sciences, Philadelphia.
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Geological Society of Edinburgh.
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*Kansas Academy of Sciences, Topeka.

*Leeds Philosophical and Literary Society.
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* ,, Geological Association.
,, Literary and Philosophical Society.
,, Lyceum Library.
,, Philomathic Society.
* ,, Engineering Society.
,, Astronomical Society.
,, Science Students' Association.
L'Universite Royal de Norvége, Christiana.
*Manchester Association of Engineers.
*Manchester Literary and Philosophical Society.
*Manchester Geographical Society.
Minnesota Academy of Natural Science, Minneapolis, U.S.
Musée Royal d'Histoire Naturelle de Belgique.
Museu Nacional, Rio de Janeiro.
Museum of Practical Geology, Jermyn Street, London.
*North of England Institute of Mining and Mechanical Engineers.
*New York Academy of Sciences.
Owens College, Manchester.
Patent Office Library, 25, Southampton Building, Chancery Lane, London, W.C.
*Rassegna delle Scienze Geologiche in Italia.
*Rochester N.Y. Academy of Science.
*Royal Dublin Society.
Royal Geological Society of Ireland, Dublin.
Royal Society, London.
*Smithsonian Institution, Washington, U.S.
*Société Geologique de Belgique, Liége.
*Société Geologique du Nord, Lille.
*Société Impériale des Naturalistes de Moscow.
*Société Royale, Malacologique de Belgique.
*Sociedade de Geografia de Lisboa.
*Toscana Societa di Scienza Naturali.
*University Library, Cambridge.
University College, Bangor.
,, ,, Liverpool.
Warwickshire Natural History and Archæological Society.
Watford Natural History Society.
*Wagner Free Institute of Science, Philadelphia.
Wisconsin Academy of Sciences, Arts, and Letters, Madison, U.S.A.
*Woodwardian Museum, Cambridge.
Yorkshire Geological and Polytechnic Society.

PROCEEDINGS

OF THE

LIVERPOOL GEOLOGICAL SOCIETY.

SESSION THIRTY-FOURTH.

OCTOBER 11TH, 1892.

THE PRESIDENT, MR. W. HEWITT, B.SC., in the Chair.

The Officers and Council for the ensuing year were elected.

Dr. Ricketts exhibited some examples of Cone-in-cone Structure.

The President then read his Annual Address:—

THE PHYSICAL CONDITIONS OF THE ARALO-CASPIAN REGION AS BEARING ON THE CONDITIONS UNDER WHICH THE TRIASSIC ROCKS WERE FORMED.

NOVEMBER 8TH, 1892.

The PRESIDENT, MR. E. DICKSON, F.G.S., in the Chair.

The following were exhibited and described:—

Mammalian Bones, &c., from the Soil Bed on the Leasowe Shore. By Mr. C. E. Miles.

Stone, believed to be from Darley Dale, Derbyshire, used in the construction of St. George's Hall. By Mr. J. J. Fitzpatrick.

Phonolite from Traprain Law, Limburgite from Haddington, N.B., and Radiolarian Chert, from the Pentland Hills, and other Rocks. By Mr. J. Lomas, A.R.C.S.

The following Paper was then read :—

THE DRIFTS OF MOEL TRYFAEN AND THE COAST OF NORTH WALES.

By T. M. Reade, C.E., F.G.S.

DECEMBER 13th, 1892.

The President, Mr. E. DICKSON, F.G.S., in the Chair.

Mr. W. Whitaker, F.R.S., F.G.S., &c., Geological Survey, proposed by Dr. Ricketts, F.G.S., and W. Hewitt, B.Sc., was elected an Honorary Member; and Mr. D. Tweddle, Walmer Road, Waterloo, proposed by H. C. Beasley and E. M. Hance, LL.B., was elected an Associate.

Mr. H. Ashton Hill, C.E., exhibited an improved form of Clinometer.

The following Papers were then read :—

NOTE ON THE DETERMINATION OF THE SPECIFIC GRAVITY OF ROCK SPECIMENS.

By P. Holland, F.I.C.

THE GLACIAL DEPOSITS ON THE SHORE OF THE MERSEY, BETWEEN HALE HEAD AND DECOY MARSH.

By A. R. Dwerryhouse and J. Lomas, A.R.C.S.

JANUARY 10th, 1893.

The President, Mr. E. Dickson, F.G.S., in the Chair.

Edgar Morris, 21, Park Road, Southport, proposed by the President and L. Cumming, M.A., was elected an Ordinary Member.

The following were exhibited and described—

A Pebble of Chalcedony, from Puget Sound. By J. J. Fitzpatrick.

Stag's Horns from the Leasowe Shore. By H. Ashton Hill, C.E.

An unusual form of Quartz, from Norway. By L. Cumming, M.A.

Mr. Lomas described and exhibited under microscopes, several rock sections illustrating Perlitic Structure.

The following paper was read :—

SOME OBSERVATIONS ON MOUNTAIN DEBRIS.

By L. Cumming, M.A.

FEBRUARY 14th, 1893.

The President, Mr. E. DICKSON, F.G.S., in the Chair.

Specimens of Chalcedony, with cavities containing fluid, were exhibited by O. W. Jeffs, and by Dr. Grossman, a visitor.

Messrs. Dwerryhouse and Lomas exhibited under microscopes, several rock sections illustrating Spherulitic Structure.

The following Paper was then read :—

OBSERVATIONS ON THE GEOLOGY OF THE COUNTRY AROUND LIVERPOOL.

By Chas. Potter.

MARCH 14th, 1893.

Mr. J. J. Fitzpatrick in the Chair.

The Hon. Treasurer presented his Statement for the last Session.

A Specimen of Variolite from the Coast of Anglesea, naturally polished by the action of blown sand, was exhibited by J. Lomas, A.R.C.S.; and Photographs of Footprints in Triassic Sandstone in the Bootle Museum, by the Hon. Secretary.

The following Paper was read:—

SOME CONDITIONS EXISTING DURING THE FORMATION OF THE OLDER CARBONIFEROUS ROCKS.

By C. Ricketts, M.D., F.G.S.

APRIL 11th, 1893.

The President, Mr. E. DICKSON, F.G.S., in the Chair.

W. Mawby, Prenton Road East, Birkenhead, was elected an Ordinary Member.

The following were exhibited:—

Pebble of Quartzite, containing a Lingula, from the Bunter Conglomerate at Barr Beacon, Staffordshire. By H. C. Beasley.

A Pebble from the Nagelfluhe of Switzerland, and Fossils from the Permian Marls exposed in the Section at Skillaw Clough. By the President.

The following Papers were then read:—

NOTE ON THE SECTION AT SKILLAW CLOUGH.

By E. Dickson, F.G.S.

REMARKS ON THE FORMATION OF CLAYS.

By E. Dickson, F.G.S., and P. Holland, F.I.C.

SOME FAULTS EXPOSED AT ARNO HILL.

By A. R. Dwerryhouse, and J. Lomas, A.R.C.S.

Field Meetings were held:—

1892.

May 11.—At Thingwall, Cheshire, led by Mr. J. Lomas, A.R.C.S.

June 4-6.—At Mold and District, led by Mr. T. M. Reade, C.E., F.G.S.

July 2.—At Beeston.

Sept. 10.—At Hilbre Island.

Oct. 1.—At Hale, led by Mr. J. Lomas, A.R.C.S.

LIVERPOOL GEOLOGICAL SOCIETY,

Dr. *In account with* EDWD. M. HANCE, *Hon. Treasurer, Session* 1892-93. **Cr.**

	£	s.	d.		£	s.	d.
To Hon. Librarian's Expenses, 1890-91	0	5	4	By Balance brought forward	2	10	0
,, Boulder Committee's ,,	0	11	10	,, Subscriptions	26	15	6
,, Subscription to Palæontographical Society	2	2	0	,, ,, Arrears	12	1	6
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,, Hon. Treasurer's Expenses	0	2	0	,, Special Donations	0	15	0
,, Amount paid Tinling & Co. (Printers) on a/c	30	0	0				
,, Balance	4	18	7				
	£44	4	0		£44	4	0
				By Balance carried forward	4	18	7

Audited and found correct,

(Signed), H. ASHTON HILL.
J. LOMAS.

PRESIDENT'S ADDRESS.

THE PHYSICAL CONDITIONS OF THE ARALO-CASPIAN REGION, AS BEARING ON THE CONDITIONS UNDER WHICH THE TRIASSIC ROCKS WERE FORMED.

By W. Hewitt, B.Sc., Assoc. R.S.M.

It is only natural that the subject of the conditions under which the Triassic rocks were formed, should come up again and again for consideration and discussion at our meetings, inasmuch as these rocks constitute the main part of the solid geology of our own district; and it is desirable that societies such as this should devote a considerable share of their attention to the special study and interpretation of local phenomena and surroundings. And, as Mr. Reade has well said,* these Triassic rocks, which at first sight appear to offer so little of interest to the ordinary geological student, are found on closer acquaintance to suggest to the physical geologist some most interesting problems. For aid towards the solution of these problems, we must look to the results of the study of districts, the conditions of which at the present day seem to be in any way similar to what we may suppose to have obtained during the Triassic age.

The late Prof. Ramsay pointed to the region about the Caspian and Aral Seas as furnishing a good modern example of the conditions which he believed to have

* "The New Red Sandstone and the Physiography of the Triassic period." "The Naturalist," April, 1889.

prevailed when our Triassic and Permian rocks were being laid down. Some time ago I collected what information I could on the conditions of that and neighbouring districts, and I have thought that it might be well to put together such information, and to bring it before you on this occasion.

In writing the full history of the origin of any series of strata we have to account for (1) the source of the material or materials of which the rocks are composed, (2) the mode of transport of such materials from their original locality to that in which the beds are found, and (3) the manner of their deposition. All these problems have necessarily to be solved by means of the circumstantial internal evidence to be obtained from the nature and arrangement of the rocks themselves (including, of course, any enclosed organic remains), and such evidence not unfrequently appears to be capable of more than one interpretation. Among the characters of the Triassic deposits of our district, which have to be accounted for, and which may in turn afford some clue to the conditions under which those deposits were accumulated, may be mentioned the vast thickness of sandstone, composed of grains, sometimes angular or subangular, sometimes extremely well rounded; the very frequent cross-bedding seen in the sandstones; the occurrence of beds of breccia and conglomerate, and the rounded pebbles of quartz and quartzite scattered throughout some of the other beds; the lumps and thin beds of marl enclosed in, or intercalated with, the beds of sandstone, and the great thickness of marl occurring at the top of the series in some parts of the district; the deposits of rock salt associated with the latter beds of marl; the prevalent red or yellow colour of the strata; the occurrence at several horizons of ripple marks, sun-

cracks, footprints, and pseudomorphs after crystals of rock salt; together with the paucity of the remains of contemporary animal and vegetable life.

Sir Andrew C. Ramsay* pointed to the deposits of rock salt and gypsum, the coating of peroxide of iron on the particles of sand and marl, the remains of land plants, the peculiarities of some of the reptiles and the occurrence of their foot-prints, as evidence that the Triassic period was essentially a continental period, and that the deposits were laid down in lakes and inland seas which may have been in part fresh water, but in the time of the New Red Marl were certainly salt. Mr. J. A. Phillips† pointed to the remarkably rounded character of the sand grains composing some of the beds as probably indicating wind action, and therefore suggesting the existence at the time of contiguous desert areas with blown sand. Prof. T. G. Bonney‡, having regard to the well rounded character of the pebbles, the confused arrangement of the beds, and the transport of a considerable amount of coarse and fine materials derived from distant sources, considers that the Bunter beds were probably formed as subærial deltas, laid down by a large and rapid river or rivers, while the Keuper beds may have been formed in an inland sea. Mr. T. Mellard Reade§ again infers from the manner in which the Triassic rocks of this country occur in embayments and straits among the older formations, from the general uniformity of the sandstone deposits over large areas, their great thickness, and the prevalence of current bedding, that the beds of the

* Quart. Journ. Geol. Soc, xxvii. p. 190, 241.

† Quart. Journ. Geol. Soc., xxxvii, p. 27.

‡ "Nature," vol. xxxiv., p. 450.

§ Physiography of Lower Trias, Geol. Mag. 1889, p. 549, and "The Naturalist," April, 1889.

Bunter were probably laid down in a tidal sea, connected with the open ocean, bordered by sand dunes and large tracts of sand-covered country, and fed with sand by large tributary rivers; while the foot-prints, ripple marks, marl beds, and salt deposits furnish sufficient evidence that the overlying Keuper was laid down in an inland lake or lakes.

I am not in a position to discuss the relative value of these several hypotheses; we probably require much more detailed information about the rocks themselves, and more still about the operation of the various agencies invoked, before we can usefully spend much time in such discussions. At the same time I fully recognise the importance to the working geologist of having in his mind some general idea as to possible explanations of the facts which he observes to characterise the particular rocks which he studies, both for the sake of assisting in the connection and co-ordination of his facts, and to put a sufficient amount of life and intelligence into his work.

Let me now proceed to put before you some facts in connection with the salt lake district of Western Asia, giving special prominence to any which seem to have a possible bearing upon those geological problems to which I have before referred.

The district known as Western Turkestan is the area which surrounds the Sea of Aral, and lies in the angle formed by the plateaus of Persia and Afghanistan on the south, and the Hindu-Kush mountains, Pamir plateau, and western spurs of the Thian Shan range on the east. In these highlands arise the few large rivers which make their way to a greater or less distance across the sandy wastes, of which the greater part of the low lying area consists, to lose themselves at last amid the

arid sands, or in some of the numerous salt lakes without outlet with which the district is in many parts studded. The two largest of these rivers—the Amu-daria (or Oxus) and the Syr-daria (or Jaxartes) have from very early times excited a considerable amount of interest and curiosity, partly from their historical associations, and partly from the tradition of the remarkable physical changes which they have undergone. These rivers are fed in great part from the melting snows and glaciers of the Pamirs and the Thian Shan range. The moisture-bearing winds from the Indian ocean are shut off from Western Turkestan by the high grounds to the S. and E., while the cold winds from the Arctic Ocean and the frozen plains of Siberia, which at times sweep with great violence over the district, are in a condition to absorb rather than to deposit moisture; hence its dry and desert character.

The Sea of Aral, with an elevation of 158 feet above the sea level, is separated from the Caspian—which is from 84 to 85 feet below sea level—by the isolated and elevated mass of the Ust Urt plateau. The expanse of low lying steppe land extending to the north, south, and east of Aral is, however, naturally connected with the vast extent of low lying country surrounding the northern shores of the Caspian, thousands of square miles of which are below sea level. The whole district is part of one of the largest areas of inland drainage in the world.

The present state of this region is far from stable, and comparatively small changes in conditions of level or of climate would suffice to bring about very considerable changes in the physical geography. And there is every reason to think that such changes on a very large scale have occurred in geologically recent

times; on which account, indeed, the district presents the geologist with a most interesting field of study. For example, from the Caspian Sea to the Sea of Azof runs the valley of the Manitch River, along which when in flood water flows in opposite directions towards those two seas. The highest portion of this valley depression is only 23 feet above the level of the Black Sea, and therefore, a rise to that extent in the waters of that sea (as, for example, by a closing of the Bosphorus), or a depression to that extent of the intermediate tract of land, would serve to restore the connection—which is believed to have existed at no very distant period—between the Black and Caspian Seas, and the waters of the former would pour over into the Caspian and cause it to overspread the vast extent of low-lying country on its northern shores. Again, the northern boundary of the Aralian steppes is formed by a low range of hills running E. and W., from near the westerly bend of the Ural River, and forming the watershed between the rivers flowing to the Tobol, a tributary of the Obi, which falls into the Arctic Ocean, and the steppe rivers flowing into the Aralian basin. According to Major Wood, this ridge is in its lowest parts only about 220 feet above sea level (or about 60 feet higher than the present level of the waters of Lake Aral), and it forms, therefore, an almost insignificant feature in the depressed tract which extends from the foot of the plateaus of Persia and Afghanistan, along the east side of the Ural Mountains, to the shores of the Frozen Ocean. Along this depression it is believed that even in post-Tertiary times the waters of a vast inland sea, which occupied a great part of the Aralo-Caspian depression, were connected by a broad strait with the Arctic Ocean.

The extent and character of the lakes in any district depend upon the relation between the amount of precipitation and of evaporation. Regions of inland drainage are those in which the amount of rainfall in the drainage area is too small to supply the evaporation and in addition to fill the lake basins to overflowing; the lakes, therefore, have no outlet, and are in consequence more or less salt. The rainfall over the greater part of the district under consideration is very small. At Petro Alexandrovsk, on the Oxus (near Khiva), the rainfall, according to Dr. Landsell, is 2·7 inches in the year; at Perovsk, on the Sir-darya, it is 5·8 inches; while at the former station the evaporation in the course of the year is said to be equal to 36 times the rainfall.* So dry is the air that Major Wood says rain is frequently evaporated before reaching the ground.

The water of the rivers which take their rise in the higher ground bordering the district is in great part evaporated or lost in the sands; the lakes are salt and are rapidly drying up, and, in fact, there are traces of many which have recently disappeared. It is well known that great changes have taken place even in the last few years in the extent of Lake Aral; its level is falling, as is shown by the rapidly increasing extent of the reedy swamps and sandy shallows on its north and east shores; and this in spite of the deposit of sediment brought down by its two great feeders, which would naturally tend to shallow the lake and cause its waters to extend over a larger area. Major H. Wood states that double the present water supply brought by the Oxus and Syr would fill the lake to overflowing; while if the present supply were entirely cut off the lake would dry up in about 90 years.†

* "Nature," xxxiv., 237. † Wood, "Shores of Lake Aral," p. 114.

Except for a fringe of fertile ground at the foot of the mountains, composed of loess and of alluvial matter brought down by the mountain streams, nearly the whole of the surface of Western Turkestan is a desert, consisting either of masses of shifting sands or of stretches of bare sandy clay which is often impregnated with salt—these clayey patches being probably in some cases the dry beds of recent lakes. Vegetation is abundant only where there is sufficient moisture. On the arid sandy plains little grows except the prickly but almost leafless *saxaul* (the fuel of the nomad and the food of the camel); the *artemisia* (or sage brush of the American deserts), and similar plants; there is also an almost entire absence of animal life. On the banks of the rivers and lakes, however, are brakes and jungles of tall reeds and canes (from 10 to 20 feet high), of tamarisk and thorny acacia bushes; these and the shallow lagoons are the resort of flocks of wild fowl, while reptile and insect life is there fairly abundant.

The fact that the absence of moisture is in many places the prime cause of this barrenness is shown by the existence of well populated and thriving oases where the waters of the few rivers are capable of being used for artificial irrigation. The Khivan oasis on the banks of the Oxus, with an area of 5,000 to 6,000 square miles, has a soil composed of stiff sandy clay; and about half the total volume of the Oxus (here said to be nearly equal to that of the Nile) is, in the cultivating season, diverted into the numerous irrigation canals on the left bank, the water being ultimately lost among the sands. The river Murghab, rising in the highlands of Afghanistan, and which possibly at one time was a tributary of the Oxus, or fell into an eastward extension of the Caspian, is now spent in irrigating the Merv oasis. The

Zarafshan, in like manner also a former tributary of the Oxus, after a course of some 400 miles, is all but used up in the artificial irrigation of the territory of Bokhara, losing its last waters in two or three small lakes within 60 miles of the main stream of the Oxus.

According to Landsell,* the rivers of Turkestan are all remarkable for their velocity, continuing to flow at a rapid rate after their descent from the mountainous regions in which they take their rise; they are likewise subject to floods in spring and early summer on the melting of the snows. The Oxus, rising on the Pamir at an elevation of some 14,000 feet, has a course of about 1,300 miles, and in the flood season its current flows, even in the lower part of its course, with a velocity of six miles an hour. It brings down with it a very large quantity of sediment—chiefly fine granitic sand. Much of this sediment, in its lower course, is deposited in the irrigation canals of Khiva, to a depth, according to Wood,† of two feet in the course of the year, and leads to the necessity for the re-excavation of these canals after the cultivating season is over. Major Wood's experiments showed that the river at this point carried about 1-750th part of its volume of detritus, and he calculates that (assuming only 1-1,000th part of the volume instead of 1-750th) in 4,000 years the water of this river used for irrigation would deposit sufficient sand to cover 50,000 square miles to the depth of one yard. He also points out how by this abstraction of water the transporting power of the main stream is so diminished as to give rise to a tendency to choke itself up by a deposit of sediment, and so be driven to seek a new channel; and he believes that considerable

* "Russian Central Asia," vol. i., p. 386.

† "Shores of Lake Aral," p. 215.

geographical changes have in the past been produced in this manner. Both the Oxus and the Syr have nearly choked themselves up by the deposit of sand at the mouths of their several arms which enter Lake Aral; extensive shallows occur, and some of their former arms are now little more than rush-grown swamps.

It appears, therefore, that a small portion only of this matter carried down by the river in suspension actually finds its way to the bed of the lake. It is also worth noting, that the sediment which is so carried in, is, as a rule, so very fine, that it is said often to form a false bed on the vegetable growth at the bottom of the lake.*

General Annenkoff, the constructor of the Trans-Caspian railway, describes several old beds of the Oxus, and says that six of these ancient channels exist between Merv and the present bed of the river. Some of these former beds are supposed to be marked out by what are known as *shors*, which he describes as "rows of cavities or embanked channels, separated from one another by heaps of sand; some dry, others filled with water to the depth of 1½ or 2 feet. A succession of such shors forms a perfect representation of a river bed dried up, and in many places filled with sand."† Although doubt has been thrown upon the origin of many of the so-called former beds of the Oxus, it seems generally accepted, that from Charjui westward is an old channel, along which the Oxus or one branch of it, together, perhaps, with the Murghab and Tejend, discharged into an eastward extension of the Caspian. This channel is in parts 2,000 feet wide, the bottom consisting of clay tracts, saline marshes, coarse bright

* Wood, *loc. cit.*, p. 149.

† Scottish Geog. Mag., vol. vii, p. 77.

sand, and pebbles.* It is interesting to note that even in this old channel, as in the present channel of the river, the right bank is described as being considerably steeper than the left; the tendency of the stream having apparently been consistently to the right. The Oxus seems to have moved over a great part of the southern part of Turkestan, and in its wanderings it has doubtless poured out over the country vast quantities of sand.

The periodical floods afford the rivers another opportunity of distributing their load of detritus over a considerable tract, leaving the sandy material, on the retirement of the waters, to become the sport of the winds. The Oxus when in flood overflows its ordinary banks to a distance of from three to five miles, the turbid yellow waters rising 20 or 25 feet above the ordinary level. The Sir-darya also when in flood submerges its banks for the lower 400 miles of its course, forming reed-grown swamps from one to four miles wide.

How far the vast masses of shifting sand, which cover so large an area of Turkestan, have had their origin in river deposits of the character just described, it is difficult to say, though no doubt this is an important source. M. Lessar,† an engineer employed to survey this district, considers that this is a probable source of the sand, from the fact that the loosest sands are found near the Oxus; and the *barkhans*, or moving sandhills, are most numerous in a belt parallel with the river. Some of the sand may, however, be the result of the disintegration *in situ* of the sandstone beds, which are described as occurring here and there

* Proc. Roy. Geog. Soc., 1882, p. 219, *et seq.*

† Proc. Roy. Geog. Soc., vol. vii., p. 238.

in the district, in the same manner as it is now understood the sands of the Sahara have been formed. In recent geological times, when the glaciers of the Thian Shan mountains were more extensive (of which there are many signs) and the rivers larger, a greater quantity of material may not unlikely have been brought down by the rivers from the high lands and distributed over the plains.

Shifting sand and sand dunes of great extent form a well marked feature over a very large part of Western Turkestan. The *barkhans*, so characteristic of certain parts of the district, are described as crescent shaped hillocks, presenting their smooth and convex sides at a low angle to the north-east—the direction of the prevailing winds—the concave leeward sides being much steeper, and more broken. Vast numbers of these *barkhans*, up to 100 or 200 feet high, occur in the southern part of the region to the East of the Caspian, and again to the N. and E. of the Aral and Oxus. They are often connected together by the horns of their crescents to form long ranges, running N.W. and S.E. Constant movement is going on, and only the growth of vegetation can stop their progress. The Hon. G. Curzon* thus describes them in the Transcaspian region, "The sand, of the most brilliant yellow hue, is piled in loose hillocks and mobile dunes, and is swept hither and thither by powerful winds. It has all the appearance of a sea of troubled waves, billow succeeding billow in melancholy succession, with the sand driving like spray from their summits." It is this incessant driving backwards and forwards by the wind which results in the extreme rounding and polish of the grains, said by Sorby, Phillips, and others, to be so characteristic of

* "Russia in Central Asia," p. 56.

desert sand. Dr. Landsell* describes the sand in the district of Khokand as containing 70 per cent. of quartz, and as being extremely fine, and running almost like oil —the result, I suppose, of its well rounded and polished nature.

Dr. Landsell also describes how the little pools of the steppes catch the blowing sand, and thus begin the monticules which grow into barkhans. Prejevalsky describes† how in Central Asia "the sand and dust, driven by the wind-storms, prevalent in spring, are caught and retained by the trees, bushes, and cane-brake growing on the banks, so as gradually to raise their level above that of the adjacent land, which is constantly diminishing under the influence of the same causes; and he further describes how on the Tarim the natives often bore through these elevated river banks, and let the water of the river escape to form an artificial lake, both for the sake of the fish and for irrigation—the side channel thus made, however, soon becoming silted up.

Much of this blown desert sand must be carried into the streams and lakes, and deposited there. It does not appear to form a permanent accumulation or bed on the open wind swept plains, but may do so in sheltered situations. Mr. H. C. Beasley, in a previous session, called your attention to the remarkable range of sand-hills, 40 miles long, and as much as 900 feet high, described by Lieut. Younghusband as having been formed by the wind in a valley between two ranges of hills, in the most sterile part of the Gobi desert.§

It is difficult to over-estimate the importance of the wind as a geological agent in these dry regions of the

* "Russian Central Asia," vol. i., p. 516.

† "From Kulja to Lob Nor," p. 57.

§ Proc. Roy. Geog. Soc., 1888, p. 494.

earth. Prejevalsky speaks of the atmosphere in the neighbourhood of Lob Nor as generally "charged with dust resembling fog or smoke,"* while in the storms the clouds of dust obscure the sun. Lieut. Younghusband attributes the heavy haze which perpetually hangs over the Kashgar and Yarkhand districts to the dust in the air raised by the strong winds, and he describes the outer ranges of hills at the foot of the Pamirs as covered with a thick deposit of mud and clay, which he believes to be nothing else than this same dust of the desert.† And Col. Tanner, in a paper on the Himalayas, says that "during the spring and summer the atmosphere is so loaded with dust that it sometimes rains muddy water . . . and the snow, up to 19,000 feet, is quite discoloured with it."‡

It would be interesting to know how far the wind is able to move small stones, and so act in rounding them. M. Moushketoff in his Geology of Turkestan, states that in a very strong storm he did not see the wind move particles of more than from 1 to 2 mm. in diameter.§ Prejevalsky, however, in a description of a dust storm in Mongolia, says|| that "sand and small stones were carried through the air like hail or snow," but he does not say anything about the size of the stones. The stones in the Egyptian deserts are said to be characteristically pitted and furrowed by the action of wind driven sand, but it would hardly appear that the wind has any rounding action on other than very small particles.

Lake Aral—next to the Caspian, the largest, and perhaps the most interesting of the lakes in this district—has an area of 26,000 square miles (or nearly as large

* "Lob Nor," p. 98. † "Nature," vol. xlv., p. 354.
‡ Proc. Roy. Geog. Soc., xiii., N.S., p. 411.
§ "Nature," vol. xxxiv., p. 237.
|| Prejevalsky, "Mongolia," vol. ii., p. 219.

as Scotland), but its size is rapidly diminishing owing to the excess of evaporation over the supply. The large gulf of Aboughir, 80 miles long by 10 miles wide, which formerly existed at the S.W. end of the lake, had, in 1845, water to a depth of 3 feet at its entrance; ten years later the depth was reduced to one half its previous amount, and soon afterwards the water had altogether disappeared and the land was under cultivation. It has recently been announced that a fresh water lake now exists on this site, formed by water draining from the marshes on the Lower Oxus. According to Wood,* the dissolved matter in the Aral water equals 13 parts in 1,000, and taking the total volume of water in the lake, as stated by him, the complete evaporation of the lake would leave a deposit of mineral matter (assuming it to be all rock salt, with a specific gravity of 2·1) sufficient to cover an area of over 1,200 square miles to a depth of 6 feet. As a matter of fact, however, only about half the dissolved mineral substance is chloride of sodium.

Sir H. Rawlinson, as the result of a study of the historical notices of Lake Aral, came to the conclusion that twice, at least, during historical times the lake has entirely disappeared, owing probably to the changes in course and volume of its two main feeders, which are believed to have fallen at one time into an eastward extension of the Caspian. In fact the lake has been well described as an intermittent steppe reservoir, fluctuating between the condition of a lake and a morass. On the other hand, there are evidences of a former great extension of the lake, when its waters are said to have stood 60 feet higher than at present, and worn the sides of hills 40 miles distant, and evidences also of its connection with the Caspian and probably with Lake Balkash.

* "Shores of Lake Aral," p. 114.

Lake Balkash, the next largest sheet of water in this district, has now an area of 8,000 square miles, but was formerly much larger, embracing in its extent Ala-Kul and several of the smaller lakes in the neighbourhood. It is believed to have been connected both with the Aralo-Caspian Mediterranean on the one hand, and with the similar inland sea of Central Asia on the other. It has now no outlet, and is intensely salt. It is very shallow, and the vast quantity of detritus brought down by the Ili and smaller streams from the mountains lying to the south, is rapidly extending the shoals on its southern borders. The effect of matter brought down in this way into lakes which have no outlet will be, by raising the bed of the lake, to increase the area of the water-spread, and so increase the amount of evaporation, thus tending in a two-fold manner towards the disappearance of the lake. The tendency of lakes in process of desiccation to break up into a number of smaller separate basins is well shown in connection with Lake Balkash and Alakul (now itself formed into three small lakes), which lies 60 miles distant; and it is also worthy of note that in Jelanashkul, a small lake some six miles long by two and a half miles wide, lying a short distance to the south of Alakul, the waves have piled up a regular embankment of small pebbles, and that it is separated from a contiguous lake by a narrow stony ridge built up in this manner;* the material being presumably supplied by the small mountain streams by which the lakes are fed. The country laid bare by the desiccation of Lake Balkash is described as consisting of sand and clay, more or less impregnated with salt.

Throughout the whole of Central and Western Asia,

* E. Delmer Morgan, in Prejevalsky's "From Kulja to Lob Nor," p. 192.

there is every sign of a great and rapid desiccation of the lakes going on, which process has been in operation some considerable time, as shown by the fall (in some cases as much as 200 feet) in the level of their surfaces; but there is also evidence that this condition is, geologically speaking, quite recent, and that it points to a very great change of climatic conditions. According to some writers, the setting in of this arid climate followed upon the recent upheaval of the Siberian plains, which even in the Quaternary period, in the western parts at least, were covered with the waters of the Northern Ocean. We cannot, however, think of the two former great Mediterraneans of Asia to which reference has been made, without being reminded of the large Quaternary Lakes of the Great Basin of North America; which, like their Asiatic counterparts, are now represented in a similar area of inland drainage by comparatively small and scattered salt lakes (the Great Salt Lake, Lake Utah, &c.) The history of some of these old lakes has been exhaustively studied by the American geologists, and it would appear that their most marked extension was coincident with the glacial epoch, which in these western regions was rainy rather than icy. In the same way there are evidences throughout the Western Thian Shan range (as well as in the Himalayas) of a former great extension of the present glaciers, which would lead to an extension of the rivers and lakes of the district, and may perhaps account, in part at least, for the existence of these vast inland seas, which are now represented under the changed conditions by Aral, Balkash, and numerous smaller bodies of salt or brackish water.

There is some uncertainty about the exact limits of the inland sea which existed in the Aral-Caspian region

in post-Tertiary times, and whether it formed one vast continuous sheet of water, or consisted, as Moushketoff thinks, of several separate basins connected by outlets.* (Unfortunately the researches of the Russian geologists into this matter are recorded in the Russian language, and are therefore a sealed book to most British geologists.) That such a sea did exist, however, is proved by the deposits of sandy clay, with shells of species now living in the Aral and Caspian, which are found over a great part of the district to the north and east of the Aral. The Ust Urt plateau and the Mougodjar hills probably interrupted the continuity of the enlarged Caspian and Aral Seas in their northern extensions; a broad gulf of the Caspian extended up the valley of the Volga, and another eastward from the southern parts of the Caspian between the Great and Little Balkan hills, probably having also connection in this direction with the Aral. Into this latter extension of the Caspian the Oxus may have fallen. Along the valley of the Manitch River an arm of the Caspian extended to the Black Sea, while, as before mentioned, there was probably an outlet to the Arctic Ocean along the eastern foot of the Ural mountains. Caspian deposits consisting of brown or yellow sandy clays, are found up the valley of the Volga, and in its tributary valleys, as far north as 55 degrees 23 minutes latitude, where in the valley of the Kama they reach a height of 530 or 540 feet above the sea.* They contain undoubted Caspian shells, and are believed by the Russian geologists who have studied them to indicate a gulf-like extension of the Caspian, 600 miles at least north of its present shores.†

* "Nature," vol. xxxiv., p. 119.

†Mem. Kazan Society of Naturalists. "Nature" vol. xliii, p. 282.

There is reason to suppose that the Aralo-Caspian district in late Tertiary times was overspread by a sea in direct and full communication with the ocean, and probably the Caspian may be regarded as a relic of this connection, separated from the main ocean by terrestrial movements. (That the salinity of a lake is in itself no proof of any former oceanic connection is, however, shown by the fact that Gilbert has estimated that the 400 million tons of sodium chloride contained in the Great Salt Lake of North America would be supplied by the existing rivers and springs entering the lake in a period not exceeding 25,000 years.*)

It has long been a tradition that the opening of the Straits of the Bosphorus is, geologically speaking, a comparatively recent event, and that previous to that time a rock barrier existed which cut off the Black Sea from the Mediterranean. The vast system of drainage now pouring into the Black Sea and Sea of Azov—the rivers Danube, Don, &c.—would thus be impounded, and as a result the water-spread of the Black Sea would be extended, more or less, over the plains of S.E. Europe; while at the same time it would, as before pointed out, even with a small rise, communicate with the Caspian by the Manitch valley—this fact, coupled with a less limited rainfall, might give rise to a great inland Aralo-Caspian Sea, which might discharge its surplus waters, either continuously or intermittently, along the east side of the Urals into the Northern Ocean. To the rupture of this rocky barrier, and the formation of the comparatively narrow Bosphorus (only about one-third of a mile at its narrowest part), the drainage and disappearance of this Aralo-Caspian Sea has frequently been ascribed, while

Gilbert, "Lake Bonneville." Monograph, U.S. Geol. Survey, p. 257.

attempts have been made to connect this event with the traditional deluge of Deucalion. Certainly there must either have been some such barrier, or else considerable changes of level, to account for the possibility of a sea embracing the present Aral and Caspian. The existence of the Caspian deposits in the Valley of the Volga, at a height of over 500 feet, would seem of necessity to indicate considerable changes of level. Such changes would, perhaps, explain how the Mediterranean of late Tertiary and early Quaternary times, which undoubtedly existed in this area, was cut off from direct communication with the ocean, while the subsequent desiccation (which, as before stated, is by some writers considered to be a result of the elevation of Northern Asia,) would explain the breaking up of that Mediterranean into the isolated basins which we now find.

In connection with the usual coloration of our Triassic rocks, it may be pointed out that in the descriptions of these districts which I have seen there is little or no reference to recent sand or clay deposits with a markedly red colour, although large tracts have been laid bare by the partial or complete disappearance of lakes. To the north of Aral lies the Kara-Kum, or Black Sand Desert, while to the S.E. lies the Kizil-Kum, or Red Sands. According to Moushketoff, in the middle parts of this desert of red sand the Aral Caspian deposits are wanting,* while other authors describe the hills in this desert as being capped with ferruginous sandstone, by the disintegration of which the red moving sands may possibly have been formed. M. Lessar† states that in many of the shors or depressions which exist between the

* "Nature," vol. xxxiv., p. 119.

† Proc. Roy. Geog. Soc., vol. vii., p. 231., *et seq.*

Caspian and the Oxus, the bottom is covered with a red, yellow, or violet ferruginous sandy soil, with gypsum, and with brackish water at or near the surface; but the origin of these hollows does not appear very evident, though as previously mentioned, they have been in some cases considered as representing the former course of the Oxus, or other river. In the Transcaspian region the sand is described as being of a bright yellow colour, and some of this may have been laid down in the extension of the Caspian, to which reference has been made above, but much of it may also have been accumulated as river and flood deposits.

According to Landsell the brackish lake Issik-Kul has a large quantity cf black iron ore covering its bed, which is thrown up on the shores in the form of sand, and collected for the extraction of the metal.*

Mr. Israel C. Russell, in a bulletin of the U.S. Geological Survey, on the "Subærial decay of rocks, and origin of the red colour of certain formations," calls attention to the general red colour of the residual deposits arising from the decay of many rocks in warm humid regions, and shows that the minute fragments of the rocks produced by mechanical disintegration in such districts are coated with a red incrustation rich in ferric oxide and alumina. In discussing previous hypotheses as to the origin of the red colour of certain geological formations, he points out that facts do not support Prof. Ramsay's hypothesis, and that "lacustral deposits in general are not characterised by a red colour;" . . . . "the sediments now forming in the saline and alkaline lakes of the arid regions of the Far West are not iron stained."† His own theory that the red

* "Russian Central Asia," vol. i., p. 158.

† Bull, U.S. Geol. Survey, No. 52, p. 47.

colour of the sands forming the red sandstones of certain formations "received their incrustation of ferric oxide during the subærial decay of the rock from which they were derived,"* while possibly true of rocks composed of angular grains which have been little if at all water-worn, will scarcely hold good for the majority of our Triassic rocks, where the constituent grains have been subjected to so much attrition. The very irregular distribution of the ferruginous colouring matter in many of the Triassic beds would rather suggest that the colouring substance may have been introduced subsequently to the laying down of the deposits.

With reference to the occurrence of pebbles and more or less coarse bedded materials in the Triassic series, the following facts may be noted.

It is a common observation of travellers in the higher regions of Central Asia that a vast amount of fragmentary material accumulates on the slopes of the mountains and in the valleys, the product of some of the agents of disintegration—especially frequent and extreme variations of temperature—which in these high, arid, and exposed regions are very active and powerful. This, and the want of sufficient means of transport, leads to the great accumulation of the detritus in particular localities. Thus Lieut. Younghusband, speaking of the Altai Mountains,† says—" In such an extremely dry climate, exposed to the icy cold winds of winter and the fierce rays of the summer sun, and unprotected by one atom of soil, the rocks here, as also in every other part of the Gobi, crumble away to a remarkable extent, and there being no rainfall sufficient to wash away the débris, the lower features of the range gradually get

* *Loc. cit.*, p. 56. † Proc. Roy. Geog. Soc., 1888, p. 494.

covered with a mass of débris falling from the upper portions, and in the course of time a uniform slope is created, often 30 or 40 miles in length." And again, in a paper read in February of this present year before the Royal Geographical Society, this same traveller describes the valleys on the Pamirs as being choked up with the débris fallen from the mountains on either side.*

Some of this material finds its way to lower levels by the agency of flood streams and mountain torrents; some of it going to form alluvial cones and other torrential deposits in the valleys and on the plains at the foot of the mountains, as described by Godwin-Austen, Drew, and Blandford in the case of the sub-Himalayan regions. Blandford, in his work on Eastern Persia, describes similar gravelly slopes extending from five to ten miles from the foot of the hills bounding the plains and valleys, while farther from the hills he found the dry plains covered with surface loamy and sandy deposits which he considered might have been formed in lakes which have since disappeared. (Recently, however, he has expressed the opinion† that a more probable origin of deposits of this nature occurring in dry regions is the wash of detritus from the hills into the plains by rain and melting snow, where the rainfall is too small to give rise to rivers able to carry away the material, the water being all evaporated within the plains.) The material composing these deposits will be of varying degrees of coarseness, the power of the sudden and short-lived torrents being immensely greater than that of an ordinary river. This is well shown by Prejevalsky's description of a sudden and violent rain storm which he experienced in the

* "Nature," vol. xlv., p. 354. † Geol. Mag., 1891, p. 373.

Ala Shan mountains*—"Streams formed in every cleft and gorge, even falling from the precipitous cliffs, and uniting in the principal ravine, descended in an impetuous torrent with terrific roar and speed. In a few minutes the deep bed of our ravine was filled with a turbid coffee-coloured stream, carrying with it rocks and heaps of smaller fragments, while it dashed with such violence against the sides that the very ground trembled as though with the shock of an earthquake. Above the roar of the waters we could hear the clash of great boulders as they met in their headlong course. From the loose banks and from the upper parts of the defile whole masses of smaller stones were detached by the force of the current, and thrown up on either side of the channel, whilst trees were torn up by their roots and rent into splinters."

Some of this material will find its way by means of occasional flood streams into the beds of any rivers which take their rise on the highlands, and be carried down into the plains. All accounts of travellers ascending the valleys of these rivers speak of the very pebbly character which they present in their descent from the mountains. The attrition and consequent rounding of the fragments in this portion of their transit will no doubt be very considerable, but it would not seem that the resulting pebbles, of any important size at least, are carried to any great distance from the foot of the hills, though, as before stated, the streams often retain a considerable velocity for a very large distance through the plains. Thus Dr. Hooker says "The great Himalayan rivers convey pebbles but a very few miles from the mountains on to the plains of India."† And in the

* Prejevalsky, "Mongolia," vol. ii., p. 264.

† "Himalayan Journals" (Minerva Library). Note p. 267.

"Manual of the Geology of India," the authors state that, in the Indo-Gangetic Alluvium, pebbles are scarce at a greater distance than from 20 to 30 miles from the hills bordering the plain.* Darwin also in his "Geological Observations on South America"† observes that in the great and rapid Santa Cruz River, in Patagonia, with a uniform current of 5 knots an hour, pebbles of compact basalt could not be found in the bed of the river at a greater distance than 10 miles below the point where the stream rushes over the débris of the great basaltic cliffs forming its shore. It would therefore seem that only in those cases where the rivers draining mountain ranges entered a lake or estuary within a comparatively short distance from the foot of the range could any considerable accumulation of pebbly deposits be formed.

* Medlicott and Blandford's "Manual of Geology of India," vol i., p. 396.

† Minerva Library, p. 298.

THE DRIFT BEDS OF THE MOEL TRYFAEN AREA OF THE NORTH WALES COAST.

By T. Mellard Reade, C.E., F.G.S.

Scope of the Paper.

The observations recorded in this paper must be taken as a continuation of those in Parts I. and II. of my "Drift Beds of the North-West of England and North Wales."*

Some of the coast districts of Carnarvonshire and Anglesey have been therein partially described already, but later and fuller observations enable me now to amplify and correct my earlier records, and present a much clearer picture of the glacial agents in these mountain districts, as I conceive them to have acted.

Moel Tryfaen and Carnarvonshire Drift.

Ever since Trimmer's discovery in 1831, the drifts of Moel Tryfaen, containing marine shells, have formed classic ground for glacial geologists. Curiously enough, although they have become a battle ground of contending theories, no very systematic account of the constitution of these drifts has yet been given to the world.

Mr. R. D. Darbishire, in 1862-3, pretty thoroughly explored the Fauna, as represented by the shells—mostly fragmentary—but no one seems to have applied as much diligence to the examination of the drift itself, although far-reaching theories have been based upon it.

The late Sir Andrew Ramsay, in 1859, inferred from the Tryfaen drift, and other drift in the neighbourhood

* Q.J.G.S., vol. xxx., pp. 27-41, and vol. xxxix., pp. 83-132.

of Llanberis, and on the moor of Ffridd Bryn-mawr, in which he found marine shells at a height of about 1,000 feet above the sea, that a great submergence, perhaps to 1,800 feet, had taken place. In 1878 he published the 5th edition of his "Physical Geology and Geography of Great Britain," where at page 415 he further discusses the question in a very interesting manner.

In 1881 the late Mr. Daniel Mackintosh read a paper before the Geological Society on the high-level marine drifts, in which the drifts of Tryfaen are dealt with more in detail than by any previous author, but there is no attempt to connect them with the drift exposed on the coast. The paper is well worth reading, and shows considerable acumen and his well-known powers of observation. The late Mr. Thomas Belt in a letter to "Nature," in May, 1874, page 26, contended that the high-level marine shells of Tryfaen "are just where they ought to be found on the supposition that an immense body of ice coming down from Northern Ireland, from Scotland, and from Cumberland and Westmoreland, filled the basin of the Irish Sea, scooped out the sand with the shells that had lived and died there, and thrust them far up amongst the Welsh hills that opposed its course southward, and around the great bight of which Liverpool forms the apex"—concluding by expressing the opinion that there are no evidences of subsidence beyond 100 feet. These or somewhat similar views have been adopted since by the late Professor Carvill Lewis, by Dr. Wright, and a few American geologists, and by their followers in this country.

For those who wish to study the history of the subject further, I append references to the leading authors who have written on the Tryfaen Drifts.

My first examination of these interesting deposits was in 1872, and a brief record appears in Part II., "Drift Beds of the North-west of England and North Wales" (Q.J.G.S., 1883, p. 114). Since then the extension of the operations of the Alexandra Slate Quarry has disclosed a greater variety of sections than were to be observed on my first visit.

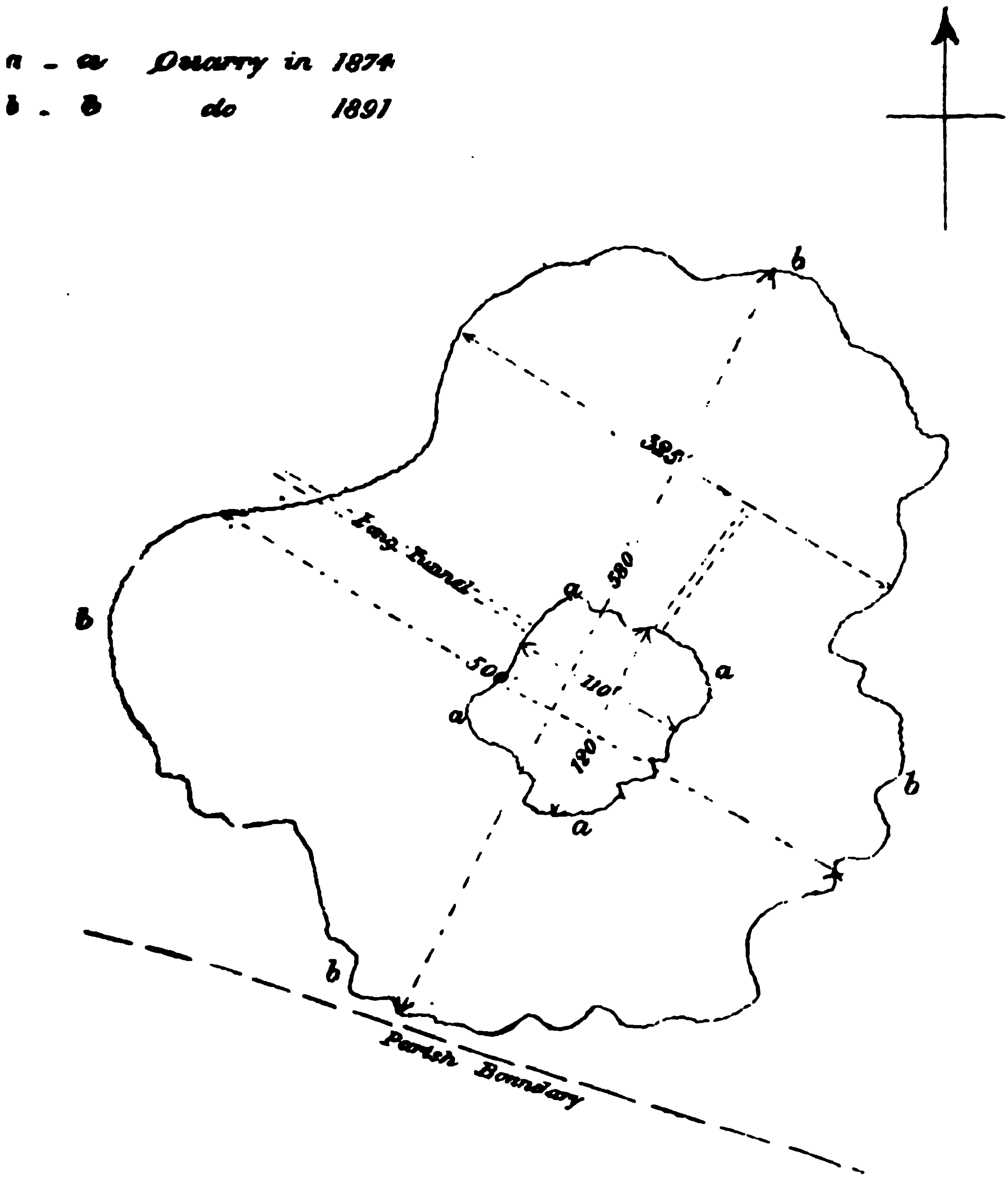
Mr. J. Menzies, the manager of the quarry, has kindly supplied me with the following sketch plan, Fig. 1, Plate 1, showing the extent of the quarry in 1874, and in 1891, from which it will be seen that the area excavated since 1874 exceeds that excavated before that date in the proportion of about 15 to 1. It naturally follows that much has since been disclosed that was hidden to the earlier observers, and these observations I propose to connect with the wide area of drift which I shall call the coastal plain.

Physiography of the Area.

The drifts about to be described are all comprised in Sheet 75 N.W. of the Ordnance 1-inch survey, but a few of the observations refer to the mountainous country at the head of the Nantlle Valley, occupying the north-west corner of Sheet 75 N.E.

From Dinas Dinlle, a mound of drift on the coast on which are situated the entrenchments of an ancient camp, to the pier of the Welsh Granite Company's Quarries at Port Trevor, near the Rivals Mountain—a coast line of about eight miles—continuous sections of glacial sands and gravels, Boulder Clay, and Till can be observed of all heights up to a maximum of 125 feet at Gwydir Bay. At no part of this length, until the Rivals is reached, can the bed-rock be seen.

Fig 1



PLAN OF ALEXANDRA SLATE QUARRY.
MOEL TRYFAEN.

From this coast-line there is a gradual rise to the foot of the mountains, varied by mammelated hills of drift sand and gravel, intermixed with Boulder Clay. This undulating plain of drift rises to a level of about 400 feet above the sea at Pen-y-groes. Midway between Pen-y-groes and Clynnog Fawr is a rather striking hill called Y Foel.

With the exception of an outcrop of slaty rock at the top, this isolated hill, rising about 650 feet above the sea level, is quite rounded over with a mantle of drift. The top is occupied with an ancient entrenched camp.

Sections of drift can be seen wherever the rivers and rivulets have cut into the mammelated hills and eskers. From Pen-y-groes to the top of Moel Tryfaen it is a pretty gradual ascent for a distance of about four miles. Looked at from the westward Tryfaen presents a low smooth conical outline, and is distinguishable from all the other hills by the circle of jagged rocks protruding from the summit (see Fig. 2, Plate 2).

From Cwm-silyn, about four miles directly south, the conical outline is still perceived, as a considerable depression separates Tryfaen from its bigger neighbour to the eastward, Mynydd Mawr (see Fig. 3). A band of Cambrian slate runs from Tal-y-sarn in a north-easterly direction over Tryfaen, and it is on this band, to the eastward of the summit, that the Alexandra Slate Quarry, which first revealed to geologists this interesting high-level marine drift, is situated.

Moel Tryfaen is about five miles eastward in a direct line from the sea. It is an outlying spur of the Snowdonian system of mountains orographically connected with Mynydd Mawr, and separated from the main mass of Snowdonia by the Nantlle Valley on the one hand, which rises to a height of about 800 feet at

the pass of Drws-y-coed, and on the other by the valley of the Gworfai, which at Llyn Cwellyn is about 500 feet above the sea. The drift of the plain already described penetrates, at a reduced thickness and in a modified form, into the Nantlle Valley, and can be seen in the slate quarries, which expose sections thereof.

To return to the coast. From the Welsh Granite Company's jetty to Nevin the coast is rocky, but from Nevin to Porth-dinlleyn fine sections of glacial drift can be seen, which rise to a height of 125 feet at the point where the road from the shore ascends to Nevin.

These drifts are mostly stratified sands and gravels, and will be more circumstantially described hereafter.

The interior mountain valleys are, as is usual, so far as we can judge, devoid of any deposits of this characteristic drift, but this feature will be more fully dwelt upon as the subject unfolds itself.

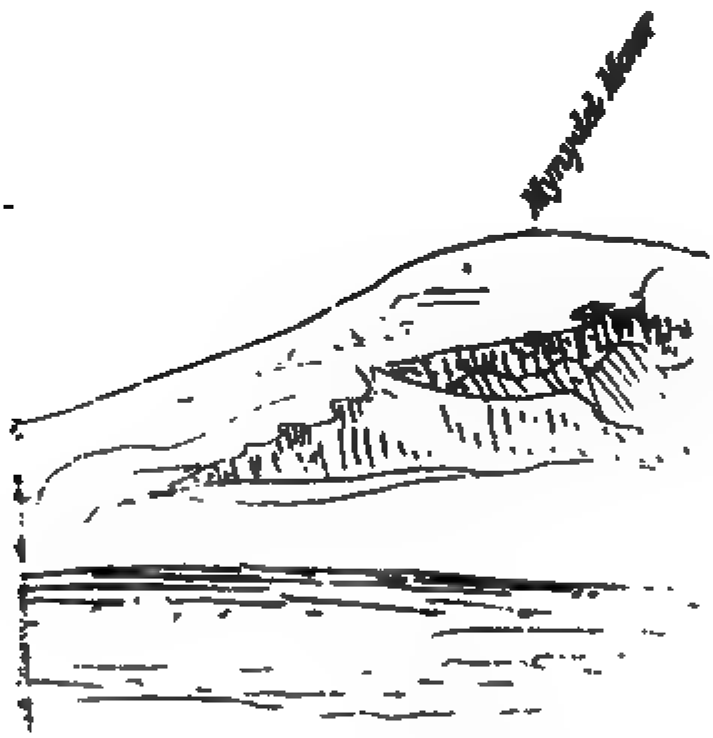
Definition of the Terms Boulder Clay and Till, in the sense used by the Author.

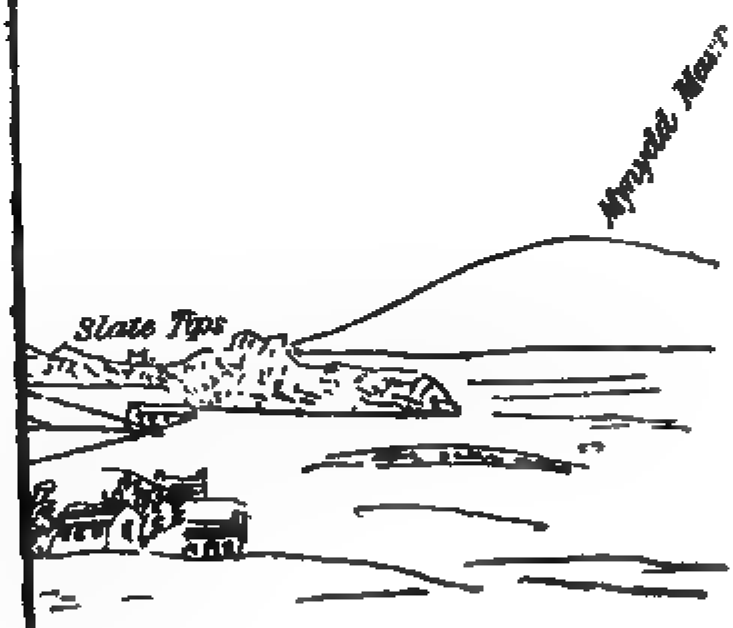
For the purposes of this paper it is necessary to define the terms Boulder Clay and Till in the sense used by the author.

Starting as he did with an investigation of the Boulder Clay of the Lancashire and Cheshire plains, which consists of a plastic reddish-brown coloured clay, used locally for brick-making, he has taken that as typical Boulder Clay. It is evidently of marine origin, whether now in the place where it was originally laid down, as believed by the author, or pushed out of it and spread over the land by an ice-sheet from the north, as held by some.

The Map (Plate 8) shews in colour, the distribution of the Glacial Drift, together with the leading features of the country and the localities described in this Paper.

PLATE 2.





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It contains numerous far-travelled fragments and boulders of a great variety of rocks (of which probably half are glaciated) and extremely few local rocks. It is a real clay, though possessing, as proved by washing, a good deal of sand and gravel, often from 40 to 60 per cent. It is also the most wide-spread deposit of the glacial drift of the N.W. of England, and exists in the greatest volume. Consequently it may fairly be taken as the typical Boulder Clay of the N.W. of England.

On nearing mountainous and hilly land, in the area treated of, this Boulder Clay is generally underlain by a deposit of a much stonier character, consisting for the most part, or wholly, of local rocks not nearly so much or generally glaciated as those in the Boulder Clay. The matrix is not argillaceous, but in consequence of the mass of stones it contains it often sets like concrete, and will withstand even the breakers. In some cases this deposit rather shades into the other like the Till, or Boulder Clay of Gwydir Bay (p. 44), (see also "Drift Beds of N.W. of England," Q.J.G.S., Vol. xxxix. pp. 123-128); in others it becomes almost a Boulder Gravel, but in every case the preponderating material is local.

Mechanical Analyses.

One of the methods of investigation adopted in the examination of the drift of the Moel Tryfaen and Carnarvonshire area was the mechanical analyses of the various beds of Till, sand, gravel, or Boulder Clay, by the separation of the granular portions by passing the material through sieves of various sized meshes, viz., 1-20th, 1-40th, and 1-100th of an inch.

The material has in most cases, but not all, been washed. The residue has been examined microscopically with 2-inch and 1-inch objectives, and a binocular

microscope, which the author finds best for this sort of work, a discovery of the *form* of the grains being of consequence.

In this way much additional light has, he hopes, been thrown upon the character and derivation of the drift constituents. In all cases where not otherwise stated, the amount of material examined was 6 oz., and the portion lost by washing is presumed to be clay.

The residue in each sieve was weighed, and the percentages calculated. The results will be found either in the body of the paper or in the appendix.

The Coast Sections.

Dinas Dinlle.—The sea has cut good sections through this mound. Commencing at the north and proceeding southward we first meet with a gravelly Till not much stratified, developing further south into gravel-and-sand beds with stiff Till intermixed. These beds are arched with a considerable dip, as shown in the accompanying figure. (Fig. 4, Plate 3). The red clay at the base of the south end proves to be very calcareous. The gravels and sands are very perfectly stratified, and contain many small rounded flakes and fragments of slate, which are quite a distinguishing feature.

At the south end of the first section the sands and gravels are arranged as shown in Fig. 5, in a low arch, with a row of boulders lying in one of the beds. The included rocks were so far as I could judge nearly all local. I did not observe any granites. The constitution of the beds and the nature and state of their component materials will be treated of hereafter, and compared with those of the other localities to be described.—*See Appendix-Analysis, No. 2.*

Fig 6.

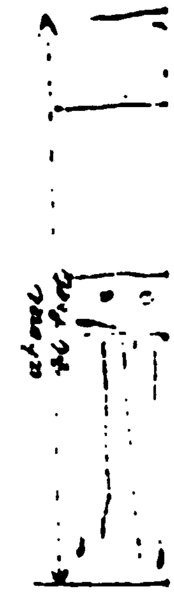
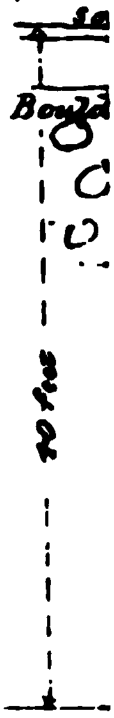


Fig 7



Point Maen-ddulan by Gored Beuno to Aber-afon.

From the section last described to Point Maen-ddulan is alluvial land, with a pebble ridge thrown up on the borders of the sea. The sections of the drift begin again at the "point" displaying stony grey Till, about 25 feet high, looser and sandier in constitution than typical Till.

On the shore and washed out of the Till I observed the following boulders:—

1.—Quartzose grit 6 ft. by 2 ft. 8 in. by 3 ft.

2.—Another, highly glaciated, of local Cambrian.

3.—Felsite, 10 ft. by 8 ft. 9 in. by 7 ft. 9 in., well glaciated on one side and rounded smooth surface, but not well striated.

4.—Dolerite, 4 ft. 9 in. by 4 ft. by 2 ft. 6 in. well glaciated and striated.

5.—Felspar Porphyry, like the "Welsh granite quarry" rock.

6.—Slate Boulder.—Banded purple slate, like that of the Nantlle Valley, well rounded and water worn, 2 ft. 3 in. by 2 ft. by 1 ft. 10 in.

Near Gored Beuno.—The section shown in Fig. 6 occurs. The drift now becomes more stratified. On the shore I measured a boulder of blue Cambrian grit, 18 ft. 6 in. by 10 ft. by 4 ft. extreme measurement, but it was wedge shaped.

The Till continues further south for a considerable distance, but before reaching Aber-afon it changes to a sandier character, is more stratified, and contains shell fragments. Fig. 7 is a section at right angles to the shore.—*See Appendix-Analysis, No. 3.*

Aber-afon to Gwydir Bay and Port Trevor.

The Afon here cuts through and displays good sections of the stratified sands and gravels. On the left bank, a little way from the mouth of the stream, a section is seen showing a basal bed of red clay with

stones, above which lie a large development of well stratified sands, having hard bands intercalated therein. Some of them are really a hard rock through cementation with carbonate of lime. Proceeding southwestwards along the shore, stratified laminated stoneless sands occur in which are inserted irregular pockets of boulder gravel, often with tongues protruding into the sands altogether irrespective of the stratification (see Fig. 8, Plate 4). Well and horizontally stratified sands and gravels show next, as represented in Fig. 9. At the end of this section is a bed of sandy loam underlying laminated stoneless sand, which again underlies boulder gravel. In this loamy sand I found a fragment of *Cardium edule*. Gravels and sands now follow on, Fig. 10 giving a fair idea of their constitution as seen in transverse section.

In the little bay east of Port Trevor (Welsh Granite Co.) is a large development of purple Till 125 feet thick above the shore, and an unknown depth below. It is a remarkably homogeneous deposit, and at first sight not one in which distantly derived erratics might be expected to occur, much less fragments of marine shells; yet both of them I found. There are many blocks of grey Carboniferous limestone, some containing *Producti* and most well polished and striated; also Anglesey schist. I took out of the Till a well worn boulder of Eskdale granite 4¼ in. by 3¼ in. by 2⅛ in., also a water-worn piece of deep red granite which I suspected was a Scotch rock. Professor Judd, to whom I submitted it, says—"This fragment very closely resembles the deeper coloured varieties of the Ross of Mull granite, and may very well have come from there, but it would not be right to assert that it could have come from nowhere else." Fragments of marine shells also occurred in the Till at the point shown on section, Fig. 11.

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The top of the Till is capped with gravel and boulder gravels. On the shore near Port Trevor are seen the remains of reeds protruding from the clay or Till, showing that it had been formerly a marsh, but that the sea had encroached on and stripped it. This Till may be placed in the category of Marine Boulder Clays like those of Lancashire and Cheshire, though less pronounced in character. Among other stones I observed striated pebbles of black limestone, like those I have seen in the Till of Gorsedd-y-penrhyn, Anglesey, small rounded slate fragments and a block of purple slate with green bands 3 ft. by 2ft. by 9 in., and another 12 in. by 8 in. by 4 in.—*See Appendix-Analysis, No. 4.*

Port Trevor to Nevin.

Following the road to Nevin (at a distance of about 1½ miles south by east from the coast measuring in a bee-line) stratified sands and gravels may be seen near Llanaelhaiarn.

The elevation of these sands and gravels is about 465 ft. above the sea, and they are undoubtedly the equivalents of the sands and gravels of the coast.

The summit of the pass Bwlch-drws-encil, between the Rivals and Mynydd Carnguwch, is about 860 feet above the sea. At about a level of 800 feet above the sea, there is a gravel pit by the road. This is almost wholly composed of the native Felspathic rock of a buff colour, angular and rotten and mixed with clay from its own decomposition. There is a little quartz sand and very rounded and polished quartz grains in it, only discoverable by washing; I shall treat of this again.—*See Appendix-Analysis, No. 8.*

Coast Section at Nevin.

Commencing at the northern horn of Nevin Bay, near to the rocky headland, the drift is composed of stratified boulder gravel, lying upon a grey-coloured Till. Further south-west beds of sand and gravel occur, and still further along, a remarkable buff coloured laminated silty clay caps the cliffs. The laminations are grouped in ribands of lighter and darker hues that make the deposit very conspicuous from the shore. Part of these beds are beautifully faulted, but as I have already described this feature in the Geological Magazine * it is unnecessary for me to dwell upon it here.

These laminated beds are entirely devoid of stones. Stratified sands and gravels follow on, and these often show a contorted arrangement. Figs. 12 and 13, Plate 5, will give an idea of these beds.

The sands, and also the gravels and boulder gravels, contain fragments of marine shells. From Section 13 to the south horn of Nevin Bay the cliffs are all stratified sands and gravels. Fig. 14 is a section on the north side of the south horn of Nevin Bay, and here we may observe for the first time the junction of the drift with the rock. The rock is smooth and more rounded under the drift than on the shore, where it takes on a jagged appearance. On the south side of the south horn is to be seen, at the base of the cliff of drift, a laminated buff coloured clay lying upon a blue-grey laminated clay. What occurs above these beds was not observable, as the slope was overgrown with grass.

Further than this I did not examine the cliffs, but it is evident that they extend in an unbroken line to

* A Miniature Illustration of Normal Faulting. Geo. Mag. p 487, 1891.

NEVIN.

Fig 13

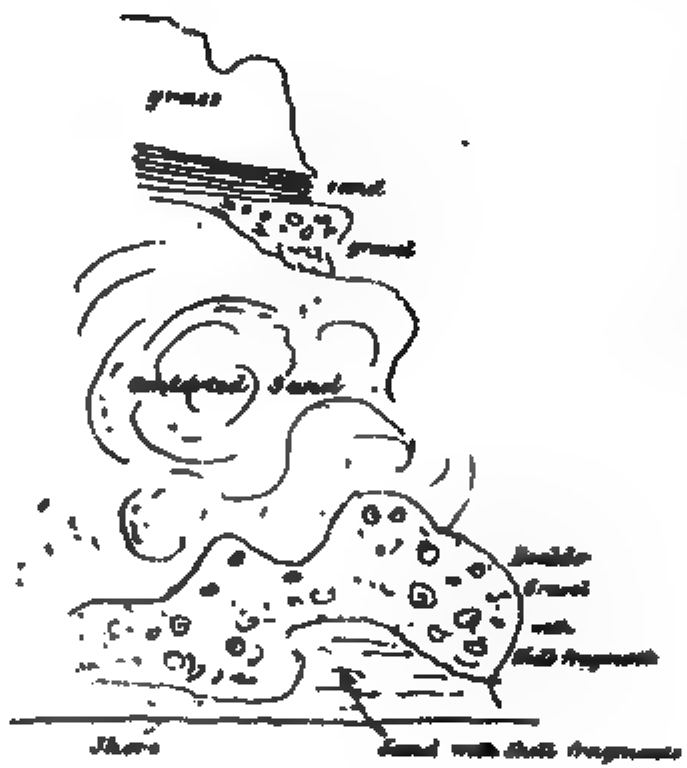


Fig 12

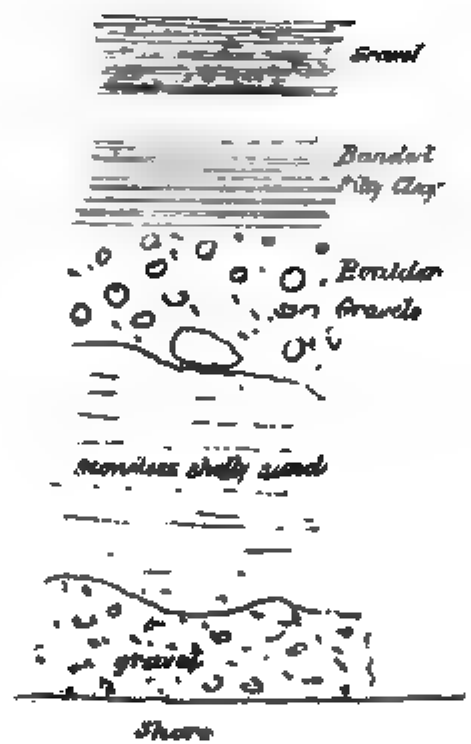
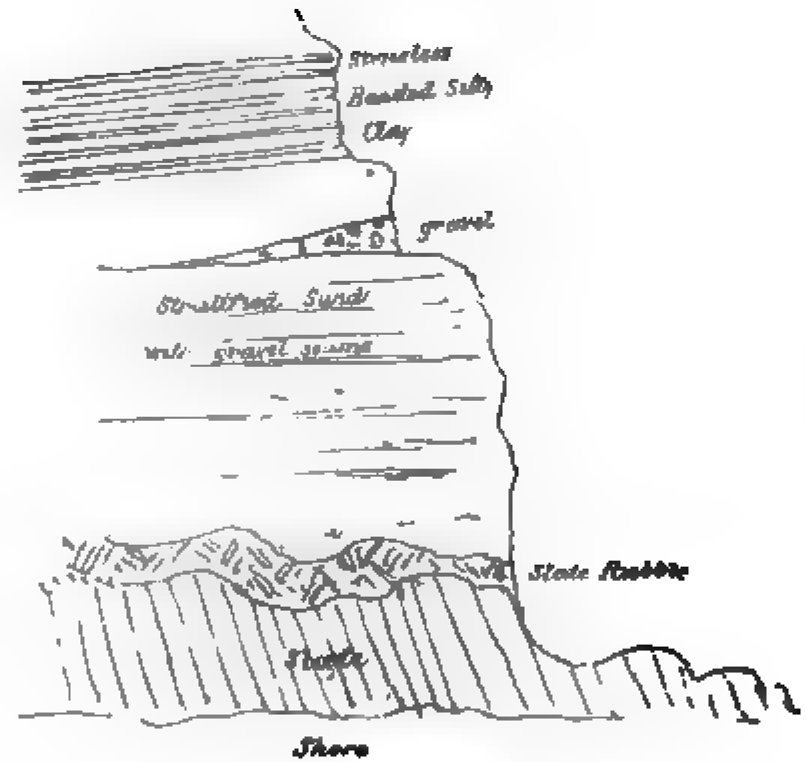


Fig 14



Porth-dinlleyn. The height of the cliff where the road ascends from the shore towards Nevin is 125 feet.—*See Appendix-Analysis, No. 9.*

Inland Sections.

Pont-crychddwr.—On the right hand of the stream Afon-ddu, just above the bridge, there is a section of typical Till at a level of about 400 feet above the sea, in which one would hardly expect to find aught but local rocks. Three small pieces of water-worn red granite, one certainly Eskdale, rewarded our search. The thin shell of a brachiopod, evidently out of the Carboniferous shale, the interior being filled with it, also occurred, together with some fragments that looked like ashy schist from Anglesey.

A section of boulder gravel and Till is to be seen on the right bank of the Afon-ddu at Tal-y-maes. Some sections may be seen on the slopes of the hills near Llanllyfni, that have been made in driving headings for slate quarrying, showing boulder gravels lying upon hard, buff-coloured, clayey till. The surface of the country about is very rugged, and the cottages are all built of boulders.

On the right bank of the Afon-ddu, below Pont-crychddwr, at a level at the base of about 350 feet above the level of the sea, is a good section of the typical Till of the neighbourhood. I judge it to be from 30 to 40 feet high. It is of a loamy and gravelly nature, and contains many boulders. We found several granite pebbles in this Till, some of them undoubtedly Eskdale. A large boulder of Anglesey schist occurred, and much quartz felsite; small fragments of slate were common, as in most of the Till about; some of them were striated. Some very large boulders are embedded in this drift.

Pant Glas.

On the left bank of the stream at Pant-glas, near Nantcyll-isaf, is a section of Till. The base is about 440 feet above the sea. I could find no erratic stones in it, but took a specimen for mechanical analysis which will be described farther on. This locality is about five miles from the coast in a direct line.

Afon Llyfni.

On the right bank of the Llyfni, above the Woollen Mill, is a good section of the Till. It is a sandy clay full of boulders and gravel. Height of section about 35 feet.—*See Appendix-Analysis No. 1.*

Mounds of Drift.

Not far from the Railway Station at Pen-y-groes is a large mound of drift, the major axis about one-third of a mile long, as near as I could judge, the direction being approximately north and south. The width is about 200 yards. It is difficult to state the height above the surrounding country from want of a base to refer it to, but the top of the mound is about 70 feet above the road at the turning to Pont-y cim.

A section showing the internal structure of this mound is to be seen in a gravel pit by the road to Pont-y-cim, not far from the station. It is composed largely of rounded stones, with sand and gravel and Boulder Clay occurring in it irregularly.

There is a circular mound, evidently of drift, between this latter place and Y Foel, called Craig-y-dinas, having a height of about 90 feet above the adjoining road. At the foot of Y Foel a small excavation dis-

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Note.—This may be considered a typical example of the Inland Till, so that it is unnecessary to publish the details of the other examples.

closed current-bedded sands, and very fine gravel, as well as an irregular deposit of boulders.

Y Foel.—This is a rounded hill about 640 feet above the sea. At the top is an ancient camp, the remains of the trench being visible. These drift covered hills seem to have been chosen for defensive purposes by reason of the less labour required in digging the trenches. There are several small outcrops of slate rock at the summit, having a cleavage N.E. and S.W. An erratic block of felsite is perched on the slate. I observed a very rounded boulder near the top. The whole mountain is covered with grass and heather, and there are no sections to be seen, but the outline leads one to suppose that there is a considerable deposit of drift upon it.

There are several sections of the characteristic mounds disclosed along the line of railway. It is unnecessary to describe them in detail. They are mostly gravel, or boulder gravel, and among it we found several specimens of erratic granite pebbles.

Tal-y-sarn.—A new cut for the river Llyfni disclosed a section of the gravelly drift. In the material thrown out of this cutting I found a most remarkably disc-like rounded stone of quartzite, measuring 4 inches diameter by 1¾ ft. thick.

It is very noticeable as occurring among so much angular material. The level of the cutting is about 440 feet above the sea. Sections of similar drift can be seen in most of the slate quarries, but its maximum thickness does not appear to exceed 20 feet in the bottom of the valley.

Drift of Moel Tryfaen.

The celebrated Alexandra Slate Quarry is situated

flints; of the latter there are proportionately many more than are found in the Lancashire and Cheshire drift.

Some of the rocks are striated and planed.

SANDS AND GRAVELS.—In the sands and gravels are numerous small shell fragments, almost invariably water worn. The shells seem more fragmentary than in the drift exposed in 1872, and I doubt very much if it were possible now to make such a collection as was made in 1862-3, by Mr. R. D. Darbishire.* Under the microscope, minute rounded fragments of shells as small as the sand grains can be seen amongst them. A noticeable feature is the number of stones having small gravel and some shell fragments cemented to them by a deposit of carbonate of lime. It is very probable that this carbonate of lime is due to the chemical destruction of some of the shells. Some seem to decay, while others get partially fossilised.†

TILL.—The most striking drift feature to be seen now occurs at the north-east side, where typical unstratified Till may be seen overlying marine sands and gravels. In one section laminated marine sand may be seen

* Mr. R. D. Darbishire has kindly examined the shell fragments found by my son Aleyn on this expedition, and has identified the following species:—

Mya truncata.	*Cardium edule.*
Tellina balthica.	*Dentalium entalis.*
Mactra.	*Turritella terebra.*
Cyprina islandica.	*Buccinum undatum.*
Astarte (sulcata ?).	*Fusus antiquus.*
Cardium echinatum.	

The remainder of the fragments were not characteristic enough for identification. All of these species are found on the Blundellsands shore at the present day, and none of them are new to Moel Tryfaen.

† Mr. Darbishire informs me that he gave to Prof. Judd a complete set of the Moel Tryfaen shells for the use of the School of Science.

A comparison of Darbishire's list with mine from other localities will be found in The Drift Beds of the N. W. of England, Q.J.G.S., vol. xxx., p. 30.

penetrating this Till, and at another place a pocket of sand is enclosed in the Till itself (see Fig. 15, Plate 6). East of this latter section the Till is seen lying upon stratified current-bedded marine sands, with shell fragments (see Fig. 16.) At another point, where a cutting has been made for the tramway to the tips on the east side, Till may be seen tongued into stratified marine sands.

The unstratified Till contains a much larger number of boulders of local rocks tightly packed together, and only a few erratics. The colour of the Till when dry is a light buff, and it powders the fingers when handling it.

The presence of this Till is a very striking feature, as I had never before observed typical Till overlying undoubted marine sands with erratics.* I took samples of the Till, enclosing the pocket of sand, on two occasions. One sample (A) on washing yielded 84 per cent. of gravel and sand, and the other (B) 62 per cent., so that the rocky constituents of the Till, reckoning in the boulders, must be very great indeed, The proportion of the materials in 6 oz. were as follows:—

* Mr. J. Menzies informs me that the "Boulder Clay" (Till) commenced about 220 feet from the south-west end of the quarry. When I inspected the excavation in 1872 I did not observe any Till, only sands and gravels. A somewhat similar but not so striking an arrangement of beds occurs at Dinas Dinlle, on the coast (Section Fig. 4, Plate 3). I find that Mackintosh, in his papers on High-Level Drifts, already referred to (Q.J.G.S., 1881), speaks of Boulder Clay about 10 feet in thickness overlying 10 feet of sand and gravel (p. 354), and he gives a section (p. 355) showing Boulder Clay above contorted layers of sand. Ramsay, in his "Physical Geology and Geography of Great Britain," 1878 (second edition), gives a section (p. 413) showing Boulder Clay capping sand and gravel. Geo. Mag., 1864, vol. i., p. 295, describes the clay as from 6 to 15 feet. Attention is not, however, called to the striking difference between the contained stones in the Boulder Clay and those in the sands and gravels.

A.

SPECIMEN A. (FIG. 15).

			Grains.
Caught in	1-20 inch mesh	.. ..	1640
,,	1-40 ,,	.. ..	160
,,	1-100 ,,	.. ..	215
Passed	1-100 ,,	deposited by subsidence	420
			2435
Clay	.. .. ..	.. ..	445
			2880

B.

SPECIMEN B. (FIG. 15).

			Grains.
Caught in	1-20 inch mesh	.. ..	870
,,	1-40 ,,	.. ..	170
,,	1-100 ,,	.. ..	250
Passed	1-100 ,,	deposited by subsidence	520
			1810
Clay	.. .. ..	.. ..	1070
			2880

It will be seen that the gravel is the most variable constituent of the Till. In taking a sample it may happen to hold some larger stones, and this will make the gravel appear disproportionate in so small a quantity as six ounces. The smaller grains are fairly constant.

The material caught in the 1-20th inch mesh consists preponderatingly of angular and partially rounded fragments of local rocks, among which is the Eurite of Mynydd Mawr. There is a large proportion of slate fragments, some showing striations, and slate flakes, both being rounded at the edges. A few tolerably well-rounded specimens of gravel occur. The material caught in the 1-40th inch mesh consists largely of the same rocks as the preceding, with a good many schistose and felspathic grains, some angular grains of quartz, and a few extremely rounded and polished grains of quartz.

penetrating this Till, and at another place a pocket of sand is enclosed in the Till itself (see Fig. 15, Plate 6). East of this latter section the Till is seen lying upon stratified current-bedded marine sands, with shell fragments (see Fig. 16.) At another point, where a cutting has been made for the tramway to the tips on the east side, Till may be seen tongued into stratified marine sands.

The unstratified Till contains a much larger number of boulders of local rocks tightly packed together, and only a few erratics. The colour of the Till when dry is a light buff, and it powders the fingers when handling it.

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A.

SPECIMEN A. (FIG. 15).

		Grains.
Caught in 1-20 inch mesh	.. ..	1640
" 1-40 "	.. ..	160
" 1-100 "	.. ..	215
Passed 1-100 "	deposited by subsidence	420
		2435
Clay	.. ..	445
		2880

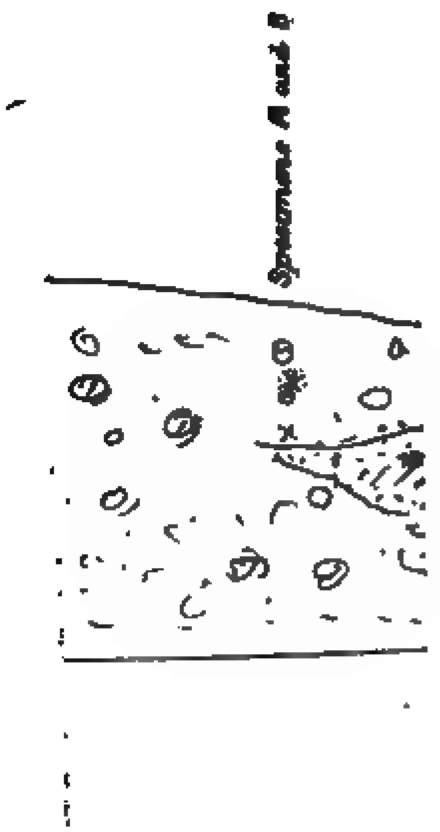
B.

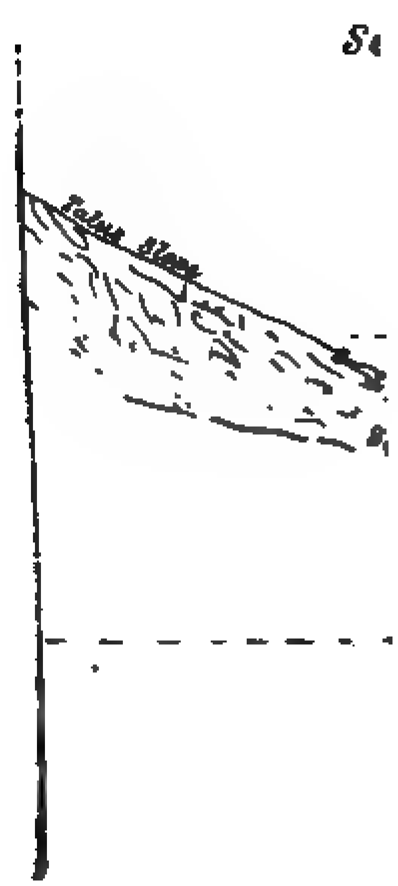
SPECIMEN B. (FIG. 15).

		Grains.
Caught in 1-20 inch mesh	.. ..	870
" 1-40 "	.. ..	170
" 1-100 "	.. ..	250
Passed 1-100 "	deposited by subsidence	520
		1810
Clay	.. ..	1070
		2880

It will be seen that the gravel is the most variable constituent of the Till. In taking a sample it may happen to hold some larger stones, and this will make the gravel appear disproportionate in so small a quantity as six ounces. The smaller grains are fairly constant.

The material caught in the 1-20th inch mesh consists preponderatingly of angular and partially rounded fragments of local rocks, among which is the Eurite of Mynydd Mawr. There is a large proportion of slate fragments, some showing striations, and slate flakes, both being rounded at the edges. A few tolerably well-rounded specimens of gravel occur. The material caught in the 1-40th inch mesh consists largely of the same rocks as the preceding, with a good many schistose and felspathic grains, some angular grains of quartz, and a few extremely rounded and polished grains of quartz.


Specimens A and B


Talus Slope

That caught in 1-100th inch mesh is like the next larger size in the nature of its component grains, but the quartz granules are in greater force. Some of them are well rounded, many roughly rounded, and others angular; as a whole, they are more rounded than the 1-40th.—*See also Analyses 5, 6, and 7, in Appendix.*

The grains that passed through the 1-100th inch mesh, and were deposited by subsidence, are nearly all quartz, non-calcareous, and the material does not effervesce with acid.

The clayey material giving the light buff colour seems to have been derived from the grinding and decay of the slate rocks.

On the north side of Tryfaen there are one or two excavations in gravel, but as the rock was not reached it is impossible to say what underlies it.

There is a gravel pit by the road on the south-west side of Tryfaen in which the stones are partly rounded and some striated. I could find no granite amongst them. Similar material with angular drift and angular blocks form the surface drift of most of the mountain.

About 400 or 500 yards east of the Alexandra Quarry there is a large boulder or angular block of a schistose felsite, measuring 40 feet by 29 feet, and 11 feet out of the ground (extreme dimensions). It must weigh some 800 tons. It is considerably weathered, especially on the east side, where it has divided into separate blocks.

Cwms.—I examined Cwm-dulyn and Cwm-silyn, on the opposite side of the Nantlle Valley, about four miles directly south of Tryfaen. These great gashes in the mountain side are evidently directly connected with the change from the slate to the massive felspar porphyry of Llwyd Mawr. Cwm-du is sculptured out of the eurite of Mynydd Mawr in a precisely similar way.

These hard igneous rocks stand the weather much better than the soft clay slates, which also get destroyed at an accelerated rate because of the cleavage. The portions of the Cwms situated in the slate are distinguished by rounded outlines, drift covered, whereas those in the igneous rock are very craggy and precipitous, possessing a characteristic solitary grandeur.

CWM-DULYN.—There are an immense number of large rounded boulders, between the lake and the Llanllyfni road immediately westward; a perfect network of walls are built of them. I measured a rounded boulder by the road, near the highest point, and found it 7 ft. 6 in. by 5 ft. 8 in.—the level will be between 600 and 700 feet above the sea. I found the lake to be 760 feet above sea level. A boulder of felspar pophyry, angular and weathered, measuring 21 ft. by 9 ft. 6 in. and 5 ft. 6 in. out of the ground, having its longer axis N.W. and S.E., or in the direction of the Valley, is to be seen below the Cwm. The cliffs of the Cwm are very grand and precipitous. Immense blocks, much larger than any boulders I have recorded here, lie about at the base. The rock splits up into cuboidal forms, and it is regularly laminated, which shows by weathering as well as in a clean fracture. It is evident that the fallen rocks have been much weathered and split up since they came into their present position; there is a great bulk of talus. The sides of the lake, below the craggy part of the Cwm, are drift-covered, and in the drift I observed some much-rounded pebbles of slate. A travelled block or boulder of the rock of the Cwm lies on the N.E. side of the lake; it measures 27 ft. 6 in. by 12 ft. 8 in. and 11 ft. out of the ground, extreme dimensions. A large block lies alongside of it on the slope towards the lake, apparently split off from it. All these large

travelled blocks are angular and unglaciated. The height of the boulder is about 870 feet above the sea. There is another block, having a pyramidal form, further to the north-west, which measures 28 ft. by 19 ft. and 13 ft. out of the ground. It is much broken up by weathering, which has probably given the rock its peculiar shape—also someone had been quarrying it. A large boulder still further N.W. is to be seen, having its surface nearly level with the ground, differing from the others in being much rounded.

CWM-SILYN.—This is a splendid Cwm and precipice. The lake is about 1,150 feet above the sea level. There are practically two small lakes, the upper one being divided by a moraine ridge (talus moraine) at right angles to the cliff in the direction of the valley. The lakes are evidently dammed up with moraine matter, though they may be rock basins also. Some of the rocks at the foot of the cliff having a very steep slope are glaciated, though as a rule there are not many signs of glaciation in these Cwms.

A travelled block lying between the lower and upper lake measured 36 ft. by 13 ft., and 10 ft. out of the ground. It appears to have been originally larger, and has split up. None of the blocks are glaciated, and all are angular, contrasting strongly with the rounded boulders at a lower level nearer Llanllyfni. The sides of the valley forming the lower part of the cwm are covered with blocks, but nothing that could topographically be called a moraine, lateral or otherwise, is to be seen.

CWM-DU.—This is a grand Cwm in Mynydd Mawr, but there are no lakes in it. A very remarkable moraine occurs here at the foot of the talus and parallel to the precipice. Fig. 17 is a section of it. Mr. Kendall has

called attention to it,* and thinks it has been formed by the talus matter from the precipice falling down a snow slope and accumulating at the foot.

It is evidently only a loose heap of angular rocky matter (mostly overgrown with heather), as the water from the Cwm filters through it instead of ponding up. I would call this type of moraine a "talus moraine." The top of the moraine is about 1,200 feet above the sea. Mr. Alfred Harker has described the Mynydd Mawr porphyry, or Eurite (Geo. Mag., 1888, pp. 221-226) stating that the rock is unique in appearance and easily recognised when met with in the drift of Moel Tryfaen and Nantlle. Unfortunately this rock was one of the last things I saw, so that I had no opportunity of studying its distribution in the drift, but since returning home have found, on washing some of my specimens, fragments of it in the drift gravel of Moel Tryfaen.

INTERIOR VALLEYS.—It only now remains for me to speak of the valleys branching from Snowdonia to the sea. These interior valleys seem, generally speaking, comparatively driftless, and I am not aware of any evidences of marine action having been found within them.

Evidences of land glaciation there are in abundance. I did not, for want of time on this occasion, make any special study of the inland area. I must leave it for a future occasion.

INTERPRETATION OF THE PHENOMENA.

EVIDENCE OF THE SAND.—It is generally assumed that the only evidence of any weight in the determination of the marine origin of a given deposit is the presence

* Notes on a Moraine-like Mound near Snowdon. Stockport Field Nat. Soc. July 18th, 1891. Report extracted from the "Cheshire County News."

of a marine fauna. Notwithstanding the uncertainty of negative evidence, if marine shells or other exuvia of the sea are not found, the deposit is often credited, if aqueous, to fresh water; that is, to rivers or lakes. In the case of the drift, however, the presence of marine shells is not considered conclusive by many glacialists of repute, who point to their generally fragmentary condition as evidence of the action of land ice.

Still it is not denied the deposits were *originally* marine, though it is assumed on theoretical grounds that these drifts are not *in situ*, but have been pushed up into their present position by great glaciers traversing the sea bottom.

The object of this chapter is to show that there is another class of evidence pointing to marine conditions which, though to my mind in the present case is as valid as the presence of marine shells, has hitherto, so far as I know, escaped observation.

For a considerable time I have been studying the phenomenon of the rounding of sand-grains, and with this object have collected a large assortment of sands from various quarters of the globe. Leaving out of account, for the purposes of this paper, sand rounded by the action of the wind, I find that the *extremely* rounded grains of sand are generally, if not universally, marine. Not even the longest rivers in the world appear to give sufficient travel and attrition to perfectly round a grain of quartz.

Sea sand, on the contrary, is often extremely rounded and polished into very regular ellipsoidal, and sometimes spherical forms. I am perfectly aware that at first blush many will consider this to be rank heresy, nevertheless it is true, being an induction from a great number of observations.

What is to be learned from Sand in the Marine Drift of Lancashire and Cheshire.

In the present connexion it is quite immaterial whether this drift is veritable undisturbed sea-bottom or sea-bottom pushed out of place by land ice,—at least among all the possibilities of the action of land ice I have never seen the rounding of sand grains attributed to it. Numerous observations of sand artificially washed out of Boulder Clay, and sand from included sand seams in the Low-level Marine drift, have shown me that there is a large proportion of extremely well rounded grains in it—much more perfectly rounded than any river sand that has come under my observation. My first doubt was whether these grains were rounded in the glacial sea or were derived from the Trias, whether in fact they were "fossil" grains; but careful investigation leads me to the rejection of this idea. Some of these drift-sand grains possess quite a brilliant polish.

Sand of Moel Tryfaen and the Drift of the Carnarvonshire Area.

It will be seen from the Appendix that many specimens (twenty in all), of the various kinds of drift described in this paper have been examined by me. The persevering labour and sharp eyes of my son Aleyn, who assisted me in the field work, and afterwards mechanically analysed the drift samples collected, have enabled me to lay information before you which otherwise I could not have done.

The sands of Moel Tryfaen consist—as shown in the detailed description in the Appendix—very largely of quartz granules strikingly rounded and waterworn.

The grains between 1-20 and 1-40 of an inch in diameter are the most perfectly shaped, some very spherical, others flattened ellipsoids. The aggregate wear which these sands exhibit is something enormous. Not only are these rounded grains found in the sand beds proper, but the unstratified Till in washing, yields an appreciable quantity of splendidly polished samples, sometimes perfectly transparent. The presence of these rounded particles amidst the angular local materials of the Till shows that they are "erratics" in every sense of the word—as much so, comprehensively speaking, as the granite pebbles from Cumberland and Scotland. A microscopic examination of a large number of specimens brings this out very forcibly.

In all the samples of Till I brought home, excepting that from Nantcyll-isaf, whether from the coast or inland, a careful washing and examination brought some of these extraordinarily rounded grains to light. Perhaps the most striking fact is the occurrence of splendidly polished quartz grains in the angular semi-decomposed gravel from near the summit of the pass between the Rivals and Mynydd Carnguwch, about 800 feet above sea level. The gravel appears to be little more than subaerial angular detritus of the rock on which it lies, intermixed with clay due to its decomposition. A more unlikely place to find extremely rounded quartz grains it would be difficult to imagine.

Evidence of the Pebbles and Boulders.

The pebbles and boulders of the Tryfaen sands and gravels are usually considerably water-worn,—not so strikingly as the sand grains, but more so than the pebbles and boulders of the Coastal plain, as I shall call

the area lying below the 400 feet contour. They also consist to a much larger extent of erratics than the drift at a lower level, and the high-level drift sands generally are more like those of Lancashire and Cheshire than are those of the coast sections. The Till which I have described as lying upon the sands, and in some cases enclosing beds and pockets of them, is unlike the Boulder Clay of Lancashire and Cheshire. The clay is not so plastic as the latter, and seems to be composed of finely comminuted and perhaps decomposed slate. The stones are much more numerous and tightly packed, and are mostly from the surrounding mountains, and finally the Till is quite unstratified, while the Boulder Clay of Lancashire and Cheshire is semi-stratified. There are planed and striated stones in all these deposits, but more largely in those of Lancashire and Cheshire.

Coastal Plain.—The drift of the Coastal plain contains a much larger proportion of local rocks than that of Tryfaen. There is an enormous quantity of slaty material in it, mostly in the form of small flakes. I consider the drift of the Coastal plain is practically the same as that of Tryfaen, modified by local circumstances. The same erratic rocks are found mingled with it, but in much lesser proportions, and granite pebbles occur in very unlikely looking deposits. The drift of local material from the Snowdonian mountains and valleys masks the northern drift to a greater extent at the lower levels. This is but in accordance with the law of gravitation. Whether the drift of the plain is continuously connected with that of Tryfaen we cannot either affirm or deny, for there is such a cover of subaerial gravels all over the mountains that it is impossible to tell what is underneath.

RECONSIDERATION AND CONCLUSIONS.

A consideration of the foregoing facts will, I think, lead us to the following conclusions:—

1.—That the drifts of Carnarvonshire, so far as described herein, represent the effects of two opposing agents, one acting radially from the Snowdonian group of mountains, the other in a northerly or north-westerly direction from the sea.

2.—The local materials derived from the adjoining high land consisting of slaty rocks, grits, and volcanic and plutonic rocks sometimes embedded in gravelly loam, and in others in a paste ground up mainly from the slaty rocks and from their decomposition, are accumulated in the greatest force at the foot of the hills and in the valleys, and are, as a rule, more angular and less rounded than the far-travelled stones. This applies to the whole of the country described, and is general in the mountain districts of Wales.

3.—Near the coast lines and extending inland, usually in decreasing proportion, stratified beds, containing foreign materials, come in. These foreign materials consist of—

Firstly, far-travelled rocks, such as granites from Cumberland, Westmoreland, and the south of Scotland, and perhaps, even from the western Highlands. These rocks are usually distinguished for their hardness and their waterworn appearance.

Secondly of sand, mainly quartz, containing a large proportion of extremely well-rounded grains, often possessing an extraordinary polish and transparency. These grains are the result of wear for an immense length of time, and represent many thousands of miles of travel of an oscillatory kind due to wave and tidal

action. They are distinctly marine, and can be distinguished from river sand by any observer who has paid sufficient attention to the subject. The contrast between these "microscopic boulders" and local grains is most remarkable, and when found mixed with angular materials drawn from the immediate area, are in the cases we are considering a proof of action of some kind from the direction of the sea.

4.—Intermediate beds consisting of unstratified Till and Boulder Clay are mixed up in places with the stratified beds, and these usually contain a mixture in varying proportions of foreign with local materials. Even in cases of what appear to be typical unstratified Till, a careful examination discloses occasional pebbles and boulders of north country granite, while washing as invariably shows the presence of the rounded grains of marine sand.

5.—The High-level sand and gravel drifts 1,300 to 1,400 feet above the sea, are composed to a larger extent of foreign materials than are the drifts of the Coastal plain, which rise in a fairly regular grade to 400 feet above the sea. The sands are remarkably rounded in the grain, and there is a large assemblage of far travelled erratic rocks in the form of boulders and pebbles of many varieties of granite; these are usually much waterworn and devoid of glacial striæ. There are also rocks, such as Carboniferous limestones and schists from Anglesey, and these are also waterworn. Compared with most of the drifts of the North-West of England and North Wales there is an abundance of waterworn and rounded flints, which are usually considered to come from Ireland, but of which the locality has never been settled with certainty. The sands are in colour, in the [redacted]dness of the grains, in the waterworn shell frag-

ments so generally distributed amongst them, and in the lamination and current-bedding, very like the sands associated with the Low-level Boulder Clay of the Lancashire and Cheshire plains, but there are not present so many of the rounded grains of various igneous rocks which distinguish the latter. The sands of the Coastal plain already described are not nearly so like the Lancashire and Cheshire drift sands, as are the high-level sands of Tryfaen.

6th.—The unstratified Till of Moel Tryfaen is a remarkable fact, and its association with the undoubtedly marine sands is very striking. In addition to containing beds and pockets of the marine sand, the sand is distributed through it, as proved by the rounded grains of quartz washed out in my analyses. The great bulk of the materials constituting the Till and the contained stones are local, and in this it offers a striking contrast to the marine beds with which it is associated.

7th.—The large angular blocks described as occurring on the flanks of Tryfaen, and on the hill sides in front of Cwm-dulyn and Cwm-silyn are doubtless the local relics of the glacial period, and synchronous with the perched blocks of Norber Brow.*

THEORIES.

But although most geologists will, I think, agree with me so far as I have yet stated the case, there are two schools of glacialists whose views as to the agencies which have brought about the phenomena radically differ. The older school look upon the sands and

* See Perched Blocks near Austwick.—Geo. Mag. 1891, p. 291-2.

gravels of Tryfaen as marine, and as indicating a submergence of the land in glacial times to at least 1,400 feet.

The newer school do not contest their original marine derivation, but maintain that they are sea bottom pushed up by a great glacier that traversed the Irish Sea from a northerly direction,* and that there has been no "great submergence," though a submergence to the extent of 100 feet is admitted by some, but denied by others.

Let us consider the bearings of the fuller facts herein detailed upon the nature of the agencies about which there can be this extraordinary difference of opinion.

The first and most obvious idea that presents itself to us is, that if the High-level drifts of Tryfaen had been pushed up by land ice from the sea, the drifts of the Coastal plain would have consisted of at least as large a proportion of travelled materials from the north as those of the High-level drifts. The facts are quite the reverse; local materials preponderate to an enormous extent in the drifts of the Coastal plain.†

The rolled and water-worn condition of the northern granite pebbles and boulders, as contrasted with the angularity of the local materials, is against their conveyance by land ice.

If we adopt the land ice explanation, we are either compelled to assume that these rounded boulders could be conveyed from the mountains of Cumberland or the South of Scotland, by a great glacier gliding over the sea bottom, without showing signs of planing or striation,

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* Those who have not already made themselves acquainted with these arguments should consult the papers of Belt, Goodchild, Carvill Lewis, and Dugald Bell, to which references are given in the "Bibliography" on page 78 of this paper.

† I find that Mackintosh had observed and made use of these facts. Q.J.G.S., 1881, p. 356.

or that the boulders are part of the deposit of the Irish Sea which the glacier ploughed up, in which case we shall have to assume for their deposit an iceberg or floating ice period preceding the Irish Sea Glacier. The same explanation would be necessary to account for the presence of Irish flints and Cumberland and Westmoreland granite, for no one land glacier could convey materials from the opposite sides of the Irish Sea, and lay them down upon the mountains of North Wales.

The argument most frequently urged against the marine theory of the drifts possessing marine shells is that the shells are in a fragmentary condition, and that were the beds in place we should have, not fragments, but complete remains of organisms in them, like what are found in the Clyde Beds. At the same time it is admitted by some who hold this view, that there has been a submergence of the North of England in glacial times to the extent of a hundred feet or more. If this be so, by parity of reasoning we should expect to find in Lancashire and Cheshire, below this level, marine beds due to the submergence, with shells *in situ* and perfect. As a matter of fact we find Boulder Clay and sands full of shell fragments—in fact, true Northern marine drift—which the same reasoners consider is sea-bed ploughed up by land ice. Either this submergence must have preceded the ploughing up, which is not alleged, or the argument fails, as no other marine beds can be pointed to.

The stratification and lamination of the High-level sands and gravels are undoubted indications of aqueous action. In what way on the land ice and non-submergence theory would this aqueous action have come about? To pond up the drainage of the land to 1,400 feet above the sea level to account for aqueous action,

or to assume that the melting of ice containing these marine materials frozen into it could act in such a way as to deposit them in current-bedded stratification on a mountain top, are hypotheses involving physical assumptions of which no proofs are as yet forthcoming.

Furthermore, we have no recorded instances of such action having been observed anywhere. If we adopt the older explanation of a great submergence, though difficulties present themselves as they do in every attempt to explain geological phenomena, the problem assumes a simpler aspect. There is no geological difficulty or improbability in the submergence itself; proofs are rapidly accumulating of much greater submergences in North America and elsewhere in late geological times.*

There is ample evidence that at one time the Snowdonian glaciers filled the valleys now terminating in the sea, and as shown by the striking glaciation at Barmouth, the Cader Idris area generated glaciers on an equally grand scale, and it would seem that they must have protruded far beyond the present embouchures of the valleys. With the subsidence of the land, the sea gradually crept up to the foot of the mountains, and during this time a continual contest raged between the sea and the land.

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* Glaciation of the Cordillera. Geo. Dawson. Amer. Geologist, 1890, pp. 153-162.

Quaternary Changes of Level. Warren Upham. Geo. Mag., 1890, pp. 492-497.

Geological Observations in British New Guinea. Jack, Memoir of the Geo. Survey of Queensland, 1892, p. 10, describes upraised Coral Reefs from only a few feet above the water to 2,000 feet above sea level.

The Malaspina Glacier. Israel C. Russell. The Journal of Geology, 1893, vol. i., p. 245, describes the finding of shells, all of living species, "on the crest of a fault scarp at Pinnacle Pass," shewing a recent elevation of the land of five thousand feet.

The glaciers occupied the valleys, retreating with increasing submergence, while the intervening high land like Tryfaen would be the freest of ice.

On the shoulders of these mountains, forming shores to the glacial sea, were deposited the marine laminated, sometimes shelly sands and gravels, identifiable as marine, as certainly by the extreme rounding and polishing of the quartz grains, as by the shell fragments and shells enclosed in them. Upon these ice-free spots the northern erratics, also well rounded, were naturally floated to and freely deposited by drift ice. As shown by the overlying Till of Tryfaen, the land and local ice after a time began to gain sway over the sea, which increased with the emergence of the land. The local materials by simple gravitation would naturally, if these conditions are granted, accumulate in the lower levels, and go largely to the formation of the Coastal plain, with its mammilated accumulations of pebbly drift, containing in less proportion than the high-level drifts, erratic pebbles and boulders, and more generally the not less erratic grains of well-worn marine sands.

The largest proportion of identifiable erratics on Tryfaen have come from high land, such as the granite mountains of the South of Scotland, Cumberland, and Westmoreland. The presence of Anglesey schists will no doubt be considered by some to favour the idea that the drift has been pushed up bodily by land-ice, but to my mind the fact can be explained just as satisfactorily by pack-ice driven on to the north slope during the sinking of the land. The water-worn condition of the fragments also favours this view.

In considering the possibilities of land-ice we must not forget that the striation of Anglesey, which is con-

sidered to represent the course of the Irish Sea ice sheet, is north-westerly, and this is not the direction required for the deposit of sea-bottom and northern erratics on Tryfaen. Nor must we forget the difficulty of accounting for the inter-crossing of erratics such as is shown on the Map, Plate 7, appended to this paper for explanatory purposes, and which has been before pointed out by Mackintosh. A reference to this Map, recording my own observations, will show that the Eskdale granite is found from Tryfaen eastwards to Cheshire and Lancashire, and the granite of the South of Scotland also. This difficulty is not lessened by the finding of a piece of undoubted Shap Fell rock on Tryfaen. These facts seem to me sufficiently telling against transport by land-ice without appealing to the travel of flints from Antrim, or of granite from the Ross of Mull or eurite from Ailsa Craig, identifications that do not possess the certainty attaching to some of the others. Professor James Geikie, in an able paper published in the "Scottish Naturalist," has attempted to account for the inter-crossing of the Scotch and Cumberland rocks by assuming a preponderance of ice from Cumberland at the commencement of the ice period, and from Scotland at a later period. If this explanation were the correct one we should find the Eskdale granite boulders in the bottom beds of the Boulder Clay of Lancashire and Cheshire, and the Scotch granites in the upper beds. No arrangement of the sort occurs; they are found indiscriminately throughout these drift deposits.

I have been much interested in reading in the "National Geographic Magazine," * published at Washington, U.S., Mr. Israel Russell's account of "an Expedition

* For May, 1891.

PLATE 7.

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to Mount St. Elias, Alaska," in which he describes the glaciers having their origin in that mountain. The Malaspina glacier, which is fed by the Agassiz, Seward, Marvine, and Hayden glaciers, is of such a volume that it has apparently displaced the sea, and holds it back by a wall of débris deposited about its margin (p. 186).

It appears to me, from a study of the phenomena Mr. Russell so well describes, that here we have a type of glacial action which, if combined with submergence and emergence, would produce the effects seen in the Moel Tryfaen area.

It will be seen that my observations go far towards confirming the earlier views of Ramsay and Mackintosh, the two observers who studied the subject in the most detail, as well as the similar inferences drawn from general reasoning by Trimmer, Lyell, and a host of other English Geologists.

APPENDIX.

MECHANICAL ANALYSES OF BOULDER CLAYS, TILLS, AND SANDS.

No. 1.—TILL, BANK OF THE LLYFNI, NEAR WOOLLEN MILL.

Weight before washing of this and other samples, except otherwise stated, was 6 oz.=2,880 grains.

	Grains.
Caught 1-20 inch mesh	1,470
,, 1-40 ,, ...	220
,, 1-100 ,, ...	320
Passed 1-100 inch (deposited by subsidence) ..	350
81 per cent. sand and gravel	2,360

Nature of materials caught by 1-20 inch mesh. Large and small gravel, one piece of striated slate, piece of mica schist, various local igneous and other rocks, sub-angular usually, some pretty well water-worn, rounded and polished grains of quartz, one 1-20 inch diameter, another 1-18 inch.

Caught in 1-40 inch mesh, waterworn schistose grains, angular pieces of quartz, some extremely rounded ellipsoidal grains of transparent quartz, mixtures of grains of igneous and local rocks, white vein quartz.

Caught in 1-100 mesh, a much larger proportion of quartz grains than in the preceding, some very angular, others cubical, and some well-worn and rounded, pellucid, saccharoidal, and yellow with a few grains of schistose and other rocks; non-calcareous.

Passed through 1-100 mesh (precipitated), nearly all quartz, some of the larger grains roughly rounded or shaped (very seldom have polish on them), small and angular, until they get as fine as flour. Faint signs of calcareous grains by treatment in acid.

NOTE.—It is quite certain that the very rounded grains are marine in origin. Such polished rounded grains mean enormous travel; nothing like them is ever seen in river sand, even from the longest rivers in the world. They are practically erratics. The angular quartz grains are probably local.

No. 2.—GREY TILL, DINAS DINLLE.

(C ON SECTION, FIG. 4).

Weight before washing, 6 oz.=2,880 grains.

	Grains.
Caught in 1-20 inch mesh	910
„ 1-40 „	170
„ 1-100 „	205
Passed 1-100 „	440
60 per cent. sand and gravel	1,725

Material in 1-20 inch mesh—Large micaceous slate fragments, rounded at the edges and striated all over; next, small slaty schistose fragments, quartz, granite and conglomerate, both rounded and angular, mostly the latter.

Material in 1-40 inch mesh.—The grains are largely angular white quartz, transparent quartz, felspar, micaceous slate, and extremely rounded and polished grains of crystal quartz; the polish is brilliant, probably the fine slate powder acted as a polishing paste.

Material in 1-100 mesh like preceding, but an increasing proportion of quartz; non-calcareous.

The material that passed through the 1-100 inch mesh is of a grey colour, largely quartz granules, covered with slaty powder—faint signs of calcareous matter,

No. 3.—GRAVELLY TILL, POINT MAEN-DDULAN.

Weight before washing, 6oz.=2,880 grains.

		Grains.
Caught in the 1-20 inch mesh	.. .. ..	1,580
„ 1-40 „	.. .. ..	155
„ 1-100 „	.. .. ..	280
Passed 1-100 „	.. .. ..	440
85 per cent. gravel and sand.		2,455

The material caught in the 1-20 inch mesh consists of subangular gravel of a greater variety of rocks than any of the preceding examples. Quartz, felsites, ashy agglomerates, and then many and various felsitic and porphyritic rocks of the Snowdonian Mountains, including the extremely laminated type, like Cwm-dulyn. Among the smaller fragments are slates—purple and blue—quartz vein, &c. Many of the stones are concreted with iron from the decomposition of the rocks. There are the usual extremely polished and rounded grains of quartz and vein quartz up to a larger size than usual. They offer a remarkable contrast to the angular materials with which they are mixed. One of these grains was fractured after rounding. Magnetite is present. The finer material follows in the same relation to the coarser, as already described in other samples.

The 1-100 material has a very few calcareous grains, which disappear very rapidly in acid. Some of the gravel is slightly striated.

No. 4.—PURPLE TILL, GWYDIR BAY.

Weight before, washing 6oz.=2,880 grains.

		Grains.
Caught in 1-20 inch mesh	.. ..	140
„ 1-40 „	.. ..	30
„ 1-100 „	.. ..	110
Passed 1-100 „	.. ..	480
26 per cent. sand and gravel.		760

The material out of the 1-20 inch mesh is to a large extent small gravel of a greenish schistose character, most probably from the Anglesey Crystalline Schists. There are quartz vein fragments, small fragments of black chert, and numerous fragments and grains of black limestone. The facies of these rocks is decidedly Angleseyan—very small rounded shell fragments occurred and three very rounded quartz grains, about 1-12 inch in diameter.

The 1-40 mesh material is to the largest extent fragmental Anglesey schist, very pretty under the microscope. A considerable number of excessively rounded and polished quartz grains, not uniform in shape, occur also, many black grains that prove to be limestone on treatment with acid, and some of a lighter colour, some fine shell fragments and angular quartz vein rock.

The materials from the 1-100 inch mesh are mineralogically the same with much yellow quartz, and a greater proportion of angular crystalline quartz, much of it stained various colours, small shell fragments, black limestone, and calcite.

The material that passed the 1-100 mesh is largely quartz splinters with calcite grains intermixed.

No. 5.—MARINE SAND, MOEL TRYFAEN,

At C, Fig. 15.

Total weight before riddling, 6 oz. = 2,880 grains.

		Grains.
Caught in 1-20 inch mesh	.. ..	1,214
„ 1-40 „	.. ..	400
„ 1-100 „	.. ..	840
Passed 1-100 „	.. ..	426
		2,880

The material caught in the 1-20 inch mesh is well water-worn gravel, quartz vein, granite, hard grit, felsite, slate, crystalline quartz, extremely well rounded grains of quartz, mostly hard rocks, mica schist.

The grains caught in the 1-40 inch mesh are generally remarkably well rounded, mostly quartz, but some of felspar or felspathic rocks; here and there are angular splints of quartz vein.

They have an eroded look on the surface, but they have not been washed; one grain perfectly spherical.

The sand out of the 1-100 inch mesh is like the preceding, and very generally rounded, but not in such perfect forms. No effervescence in acid.

The grains that have passed the 1-100 inch sieve are exceptionally well rounded for such small grains. Indications of calcareous grains by slight effervescence in acid.

Generally the sand is of a yellowish-red colour, and bears a great resemblance to the drift sand of Lancashire and Cheshire, which is mostly derived from the Trias.

No. 6.—SAND FROM POCKET IN GREY TILL, MOEL TRYFAEN.

Fig. 15.

Weight before washing, 6 ozs.=2,880 grains.

			Grains.
Caught in	1-20 inch mesh	.. ..	1560
„	1-40 „	.. ..	400
„	1-100 „	.. ..	550
Passed	1-100 „	.. ..	300
	97 per cent. sand.		2810

The material in the 1-20 inch mesh is rounded and angular gravel, mostly hard erratic rocks, one granite pebble, and some slate.

That from the 1-40 inch mesh is mostly well rounded quartz, but not polished, with a good deal of extremely hard rocks, mostly felspathic.

The grains from the 1-100 mesh are generally well rounded, of quartz, and a small proportion of extraneous rocks—grains of iron attracted by the magnet; non-calcareous.

The material that passed through the 1-100 sieve is mostly quartz, in well rounded grains, but rather dirty; non-calcareous.

The sand is practically the same as the sand beds, with a little dirt and clay in it. It is not at all calcareous, either sand or gravel.

No. 7.—SAND, MOEL TRYFAEN.

Five feet from Surface. West Side of Quarry.

Weight before washing, 6 oz.=2,880 grains.

			Grains.
Caught in	1-20 in. mesh	.. ..	810
„	1-40 „	.. ..	930
„	1-100 „	.. ..	1,030
Passed	1,100 „	.. ..	50
	98 per cent. sand	.. ..	2,820

The material in the 1-20 mesh is gravel of a sub-angular character of Welsh rocks, with angular quartz. There are some large ovoidal grains of crystalline and white quartz up to 1-10 inch, very rounded and smoothed, one or two minute polished pebbles of an undeterminable hard rock, minute fragments of flint; on one of the pebbles grains of sand were cemented by a non-calcareous cement.

The 1-40 material is largely quartz grains well rounded, some subangular and mixed with other siliceous and flinty looking grains. This sand is of about the same size and degree of roundness, taking the quartz grains alone, as a specimen of wind-blown sand from Aboosеer, second Cataract of the Nile, and rounder than sand from near the Great Pyramid.

The sand from the 1-100 mesh is like the preceding, more equal in size of grain, and equally well rounded.

The grains that passed the 1-100 mesh are of a splintery character.

No. 8.—FROM MYNYDD CARNGUWCH,

800 feet above the sea level.

Weight before washing, 6 oz.=2,880 grains.

			Grains.
Caught in the	1-20 inch mesh	.. .. ..	1,330
,,	1-40 ,,	.. .. ..	70
,,	1-100 ,,	.. .. ..	180
Passed	1-100 ,,	.. .. ..	550
	74 per cent. gravel and sand.		2,130

The great bulk of the material in the 1-20 inch mesh is a cream-coloured decomposed felspathic rock, in angular fragments; most of it will break up in the fingers; the clay washed out of it was the product of this decomposition, and dusted the fingers like chalk. Intermixed are a few small flakes of a grey slate, waterworn, and one partially waterworn grain of quartz.

No. 9.—SAND, NORTH SIDE OF SOUTH HEADLAND, NEVIN.

Weight before riddling, 6 oz. 2,880 grains.

			Grains.
Caught in	1-20 inch mesh	.. ..	300
,,	1-40 ,,	.. ..	180
,,	1-100 ,,	.. ..	2,160
Passed	1-100 ,,	.. ..	180
			2,820

The material in the 1-20 inch sieve consists of a pebble of grit, encrusted with sand and a few minute shell fragments by a calcareous cement effervescing strongly in acid; the rest is fine gravel of the usual type, intermixed with fine rounded grains of quartz and well worn shell fragments.

The grains caught in the 1-40 inch mesh are to a large extent splendidly-rounded, and polished, and there is a considerable proportion of very rounded shell fragments, only distinguishable under the microscope, and sometimes only acid will prove their nature. The sand effervesces strongly in acid; some of the grains are composite, cemented together by calcareous cement. When treated with acid it is seen the shell fragments are more numerous than otherwise would be suspected.

The sand retained by the 1-100 mesh is more largely composed of quartz grains, some well rounded. The shell fragments are not very conspicuous, but treatment with acid shows that they are numerous.

The material that passed the 1-100 mesh consisted of quartz grains, with less extraneous matter. Shell fragments are not easily detectable, but treated with acid the material effervesces violently, and it is seen that there are numerous white calcareous grains, each sending off an energetic jet of bubbles. The calcareous grains seem to have lost their shell structure.

The material caught in the 1-40 inch mesh was mostly grains of some decomposed rock, intermixed with *extremely rounded and polished quartz* grains and angular quartz granules, also a few grains of slate. Does not effervesce with acid.

The 1-100 mesh retained similar material to the preceding, but a larger proportion of angular quartz grains.

The material that passed the 1-100 mesh contained a larger proportion of angular quartz grains. Does not effervesce with acids.

The occurrence of polished quartz grains in this material is quite unexpected and striking.

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1846.—E. Forbes. Fauna and Flora of the British Isles. Memoirs of the Geo. Survey, vol. i., p. 384.

Caught in 1-40 inch mesh, waterworn schistose grains, angular pieces of quartz, some extremely rounded ellipsoidal grains of transparent quartz, mixtures of grains of igneous and local rocks, white vein quartz.

Caught in 1-100 mesh, a much larger proportion of quartz grains than in the preceding, some very angular, others cubical, and some well-worn and rounded, pellucid, saccharoidal, and yellow with a few grains of schistose and other rocks; non-calcareous.

Passed through 1-100 mesh (precipitated), nearly all quartz, some of the larger grains roughly rounded or shaped (very seldom have polish on them), small and angular, until they get as fine as flour. Faint signs of calcareous grains by treatment in acid.

NOTE.—It is quite certain that the very rounded grains are marine in origin. Such polished rounded grains mean enormous travel; nothing like them is ever seen in river sand, even from the longest rivers in the world. They are practically erratics. The angular quartz grains are probably local.

No. 2.—GREY TILL, DINAS DINLLE.

(C ON SECTION, FIG. 4).

Weight before washing, 6 oz. = 2,880 grains.

		Grains.
Caught in 1-20 inch mesh	.. ..	910
,, 1-40 ,,	.. ..	170
,, 1-100 ,,	.. ..	205
Passed 1-100 ,,	.. ..	440
60 per cent. sand and gravel		1,725

Material in 1-20 inch mesh—Large micaceous slate fragments, rounded at the edges and striated all over; next, small slaty schistose fragments, quartz, granite and conglomerate, both rounded and angular, mostly the latter.

Material in 1-40 inch mesh.—The grains are largely angular white quartz, transparent quartz, felspar, micaceous slate, and extremely rounded and polished grains of crystal quartz; the polish is brilliant, probably the fine slate powder acted as a polishing paste.

Material in 1-100 mesh like preceding, but an increasing proportion of quartz; non-calcareous.

The material that passed through the 1-100 inch mesh is of a grey colour, largely quartz granules, covered with slaty powder—faint signs of calcareous matter,

No. 3.—GRAVELLY TILL, POINT MAEN-DDULAN.

Weight before washing, 6oz.=2,880 grains.

			Grains.
Caught in the	1-20 inch mesh	.. .. ..	1,580
,,	1-40 ,,	.. .. ..	155
,,	1-100 ,,	.. .. ..	280
Passed	1-100 ,,	.. .. ..	440
85 per cent. gravel and sand.			2,455

The material caught in the 1-20 inch mesh consists of subangular gravel of a greater variety of rocks than any of the preceding examples. Quartz, felsites, ashy agglomerates, and then many and various felsitic and porphyritic rocks of the Snowdonian Mountains, including the extremely laminated type, like Cwm-dulyn. Among the smaller fragments are slates—purple and blue—quartz vein, &c. Many of the stones are concreted with iron from the decomposition of the rocks. There are the usual extremely polished and rounded grains of quartz and vein quartz up to a larger size than usual. They offer a remarkable contrast to the angular materials with which they are mixed. One of these grains was fractured after rounding. Magnetite is present. The finer material follows in the same relation to the coarser, as already described in other samples.

The 1-100 material has a very few calcareous grains, which disappear very rapidly in acid. Some of the gravel is slightly striated.

No. 4.—PURPLE TILL, GWYDIR BAY.

Weight before, washing 6oz.=2,880 grains.

			Grains.
Caught in	1-20 inch mesh	.. ..	140
,,	1-40 ,,	.. ..	30
,,	1-100 ,,	.. ..	110
Passed	1-100 ,,	.. ..	480
26 per cent. sand and gravel.			760

The material out of the 1-20 inch mesh is to a large extent small gravel of a greenish schistose character, most probably from the Anglesey Crystalline Schists. There are quartz vein fragments, small fragments of black chert, and numerous fragments and grains of black limestone. The facies of these rocks is decidedly Angleseyan—very small rounded shell fragments occurred and three very rounded quartz grains, about 1-12 inch in diameter.

The 1-40 mesh material is to the largest extent fragmental Anglesey schist, very pretty under the microscope. A considerable number of excessively rounded and polished quartz grains, not uniform in shape, occur also, many black grains that prove to be limestone on treatment with acid, and some of a lighter colour, some fine shell fragments and angular quartz vein rock.

The materials from the 1-100 inch mesh are mineralogically the same with much yellow quartz, and a greater proportion of angular crystalline quartz, much of it stained various colours, small shell fragments, black limestone, and calcite.

The material that passed the 1-100 mesh is largely quartz splinters with calcite grains intermixed.

No. 5.—MARINE SAND, MOEL TRYFAEN,

At C, Fig. 15.

Total weight before riddling, 6 oz. = 2,880 grains.

			Grains.
Caught in	1-20 inch mesh	.. ..	1,214
„	1-40 „	.. ..	400
„	1-100 „	.. ..	840
Passed	1-100 „	.. ..	426
			2,880

The material caught in the 1-20 inch mesh is well water-worn gravel, quartz vein, granite, hard grit, felsite, slate, crystalline quartz, extremely well rounded grains of quartz, mostly hard rocks, mica schist.

The grains caught in the 1-40 inch mesh are generally remarkably well rounded, mostly quartz, but some of felspar or felspathic rocks; here and there are angular splints of quartz vein.

They have an eroded look on the surface, but they have not been washed; one grain perfectly spherical.

The sand out of the 1-100 inch mesh is like the preceding, and very generally rounded, but not in such perfect forms. No effervescence in acid.

The grains that have passed the 1-100 inch sieve are exceptionally well rounded for such small grains. Indications of calcareous grains by slight effervescence in acid.

Generally the sand is of a yellowish-red colour, and bears a great resemblance to the drift sand of Lancashire and Cheshire, which is mostly derived from the Trias.

No. 6.—SAND FROM POCKET IN GREY TILL, MOEL TRYFAEN.

FIG. 15.

Weight before washing, 6 ozs. = 2,880 grains,

		Grains.
Caught in 1-20 inch mesh	.. ..	1560
„ 1-40 „	.. ..	400
„ 1-100 „	.. ..	550
Passed 1-100 „	.. ..	300
97 per cent. sand.		2810

The material in the 1-20 inch mesh is rounded and angular gravel, mostly hard erratic rocks, one granite pebble, and some slate.

That from the 1-40 inch mesh is mostly well rounded quartz, but not polished, with a good deal of extremely hard rocks, mostly felspathic.

The grains from the 1-100 mesh are generally well rounded, of quartz, and a small proportion of extraneous rocks—grains of iron attracted by the magnet; non-calcareous.

The material that passed through the 1-100 sieve is mostly quartz, in well rounded grains, but rather dirty; non-calcareous.

The sand is practically the same as the sand beds, with a little dirt and clay in it. It is not at all calcareous, either sand or gravel.

No. 7.—SAND, MOEL TRYFAEN.

Five feet from Surface. West Side of Quarry.

Weight before washing, 6 oz. = 2,8F0 grains.

		Grains.
Caught in 1-20 in. mesh	.. ..	810
„ 1-40 „	.. ..	930
„ 1-100 „	.. ..	1,030
Passed 1,100 „	.. ..	50
98 per cent. sand	.. ..	2,820

The material in the 1-20 mesh is gravel of a sub-angular character of Welsh rocks, with angular quartz. There are some large ovoidal grains of crystalline and white quartz up to 1-10 inch, very rounded and smoothed, one or two minute polished pebbles of an undeterminable hard rock, minute fragments of flint; on one of the pebbles grains of sand were cemented by a non-calcareous cement.

The 1·40 material is largely quartz grains well rounded, some subangular and mixed with other siliceous and flinty looking grains. This sand is of about the same size and degree of roundness, taking the quartz grains alone, as a specimen of wind-blown sand from Abooseer, second Cataract of the Nile, and rounder than sand from near the Great Pyramid.

The sand from the 1·100 mesh is like the preceding, more equal in size of grain, and equally well rounded.

The grains that passed the 1·100 mesh are of a splintery character.

No. 8.—FROM MYNYDD CARNGUWCH,

800 feet above the sea level.

Weight before washing, 6 oz.=2,880 grains.

		Grains.
Caught in the 1·20 inch mesh	.. .. ..	1,330
,, 1·40 ,,	.. .. ..	70
,, 1·100 ,,	.. .. ..	180
Passed 1·100 ,,	.. .. ..	550
74 per cent. gravel and sand.		2,130

The great bulk of the material in the 1·20 inch mesh is a cream-coloured decomposed felspathic rock, in angular fragments; most of it will break up in the fingers; the clay washed out of it was the product of this decomposition, and dusted the fingers like chalk. Intermixed are a few small flakes of a grey slate, waterworn, and one partially waterworn grain of quartz.

No. 9.—SAND, NORTH SIDE OF SOUTH HEADLAND, NEVIN.

Weight before riddling, 6 oz. 2,880 grains.

		Grains.
Caught in 1·20 inch mesh	.. ..	300
,, 1·40 ,,	.. ..	180
,, 1·100 ,,	.. ..	2,160
Passed 1·100 ,,	.. ..	180
		2,820

The material in the 1·20 inch sieve consists of a pebble of grit, encrusted with sand and a few minute shell fragments by a calcareous cement effervescing strongly in acid; the rest is fine gravel of the usual type, intermixed with fine rounded grains of quartz and well worn shell fragments.

The grains caught in the 1-40 inch mesh are to a large extent splendidly-rounded, and polished, and there is a considerable proportion of very rounded shell fragments, only distinguishable under the microscope, and sometimes only acid will prove their nature. The sand effervesces strongly in acid; some of the grains are composite, cemented together by calcareous cement. When treated with acid it is seen the shell fragments are more numerous than otherwise would be suspected.

The sand retained by the 1-100 mesh is more largely composed of quartz grains, some well rounded. The shell fragments are not very conspicuous, but treatment with acid shows that they are numerous.

The material that passed the 1-100 mesh consisted of quartz grains, with less extraneous matter. Shell fragments are not easily detectable, but treated with acid the material effervesces violently, and it is seen that there are numerous white calcareous grains, each sending off an energetic jet of bubbles. The calcareous grains seem to have lost their shell structure.

The material caught in the 1-40 inch mesh was mostly grains of some decomposed rock, intermixed with *extremely rounded and polished quartz* grains and angular quartz granules, also a few grains of slate. Does not effervesce with acid.

The 1-100 mesh retained similar material to the preceding, but a larger proportion of angular quartz grains.

The material that passed the 1-100 mesh contained a larger proportion of angular quartz grains. Does not effervesce with acids.

The occurrence of polished quartz grains in this material is quite unexpected and striking.

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PLATE 8

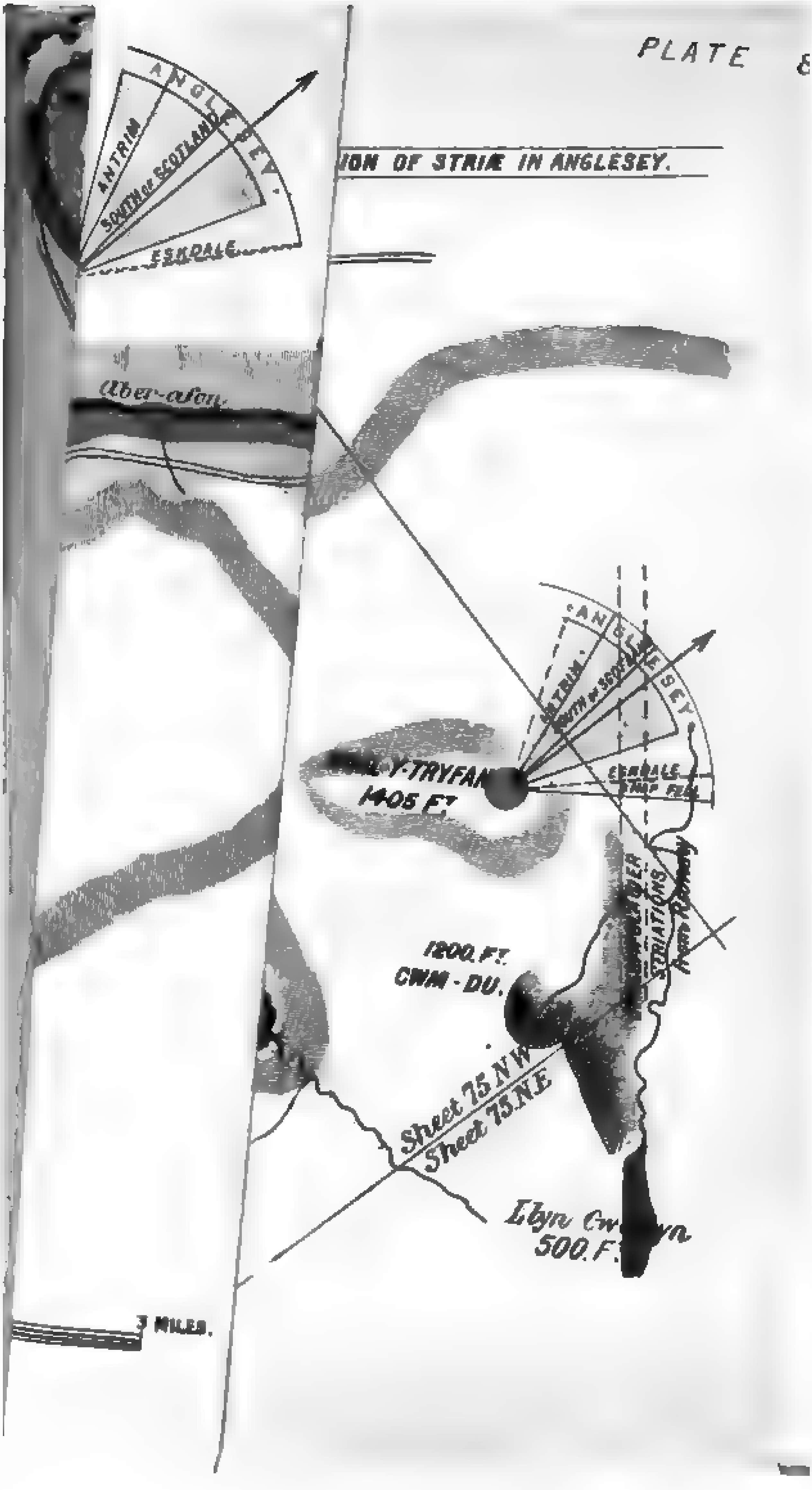
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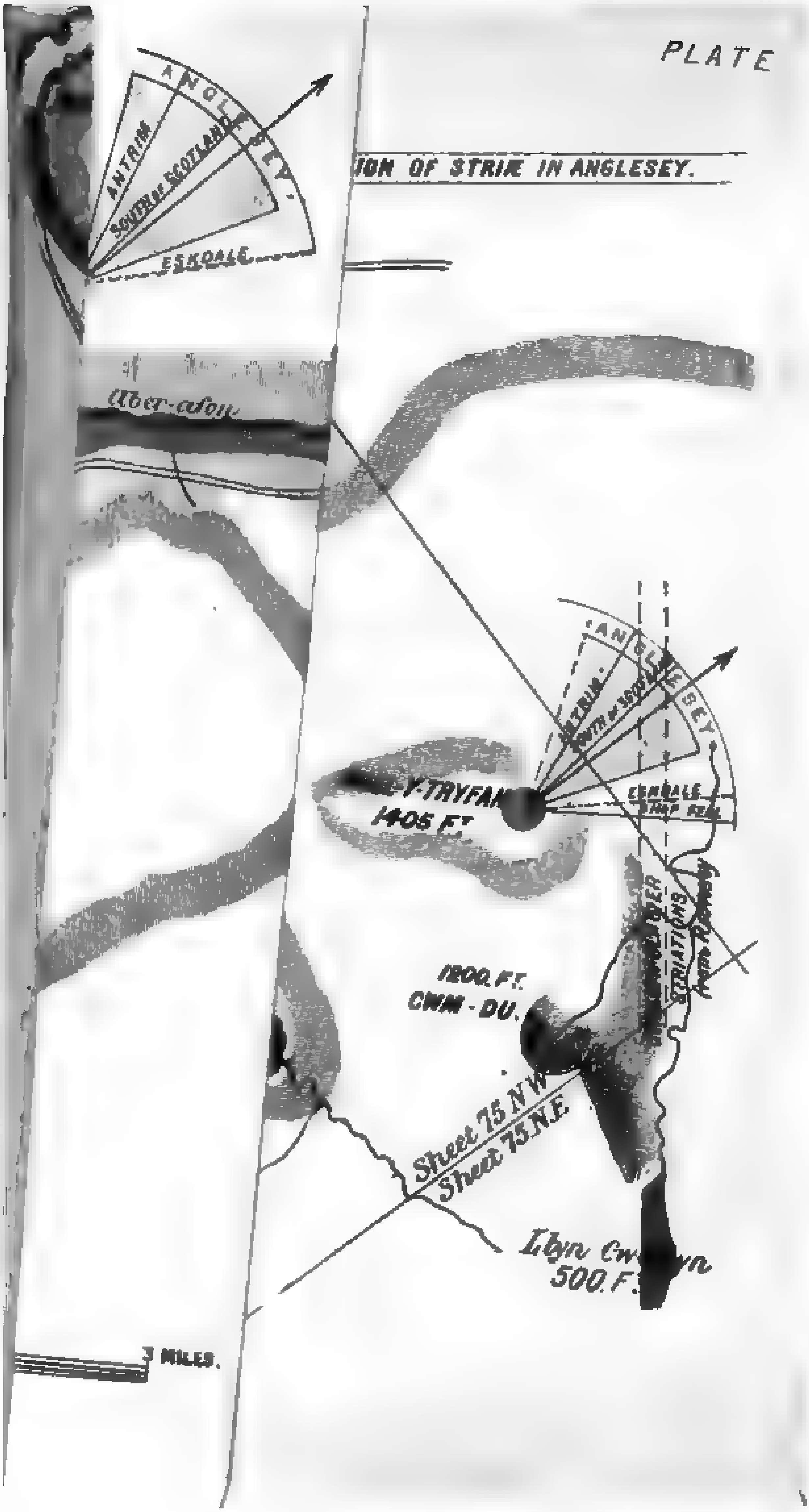
PLATE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THE GLACIAL DEPOSITS ON THE SHORE OF THE MERSEY, BETWEEN HALE HEAD AND DECOY MARSH.

By J. Lomas, A.R.C.S., and Capt. A. R. Dwerryhouse.

At the December Meeting of last year a Paper was read by one of us on the Glacial deposits between Dingle Point and Hale Head.*

In the present communication we propose to continue the description of the shore from Hale Head onwards, as far as Decoy Marsh.

Just under the Lighthouse, at Hale Head, there is a cliff of sandstone (*f.* 2 of Survey) from 20 to 30 ft. high. It is capped by soil containing numerous small erratics, which have, no doubt, been derived from the adjoining glacial deposits.

The sandstones are very much contorted, and at the top broken up, but the latter is probably nothing more than surface weathering.

In the first bay beyond the Lighthouse the sandstone is overlaid by true Boulder Clay, from 1 to 4 feet thick, and this again is succeeded by 3 feet of surface soil.

A boulder of Dalbeattie Granite, 24 in. by 18 in. is now exposed in the cliff. It is partially buried in the rock, which fits closely against its sides. The under surface is planed and grooved; the groovings have a direction of 65° W. of N. The top is smoothed but not planed, and has no distinct striæ.

The clay about contains many small stones, chiefly Andesites, Eskdale Granite, Grits, and numerous pebbles of Quartzite and vein Quartz; the latter have evidently been derived from the rocks beneath.

* (Proceedings of the Liverpool Geological Society, vol. vi.—p. 396.)

A little further on a boulder of more basic rock, probably a Diorite, is seen, measuring 12 in. by 8 in. It is totally buried in the rock, and is very much decomposed. Fig. 1, Plate I.

Twenty yards beyond, another decomposed Diorite occurs (12 in. by 6 in.). It is set with its long axis vertical. Not only is it completely buried in the rock, but it has dragged down some light coloured marl bands on each side. Fig. 2, Plate I.

In the next bay the clay thickens to 6 ft., and under the glacial deposits the rock is so much broken up that it is difficult to tell where the rock ends and the glacials begin.

In one place we have a section

2ft. soil
4ft. Boulder Clay
8in. Gravel
6ft. + Sandstone

A yard further, and the gravel has thickened to 4 ft., and the surface of the rock is correspondingly lower.

We find small pieces of Andesite and other rocks at a depth of several inches below apparently undisturbed rock, and the gravel above contains a large proportion of angular pieces of sandstone evidently torn from the adjacent beds.

A very careful examination of the rock containing the boulders tends to show that the rock has really been gound up and re-compacted. A soft crumbling rock such as this would not require much force to produce such an effect.

About the middle of this second bay a landslip has recently occurred which hides the lower deposits, but a little further on a beautiful example of a "ground moraine" is seen. Fig. 3, Plate I. Here are angular

Fig. 1.

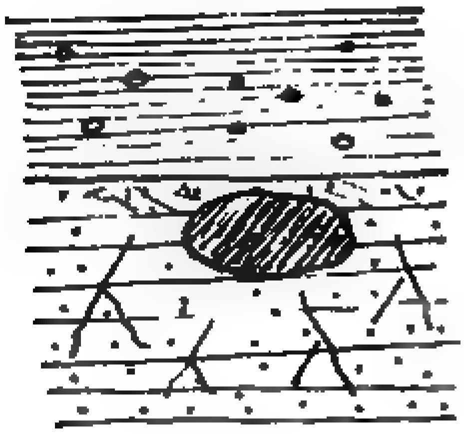


Fig. 2.

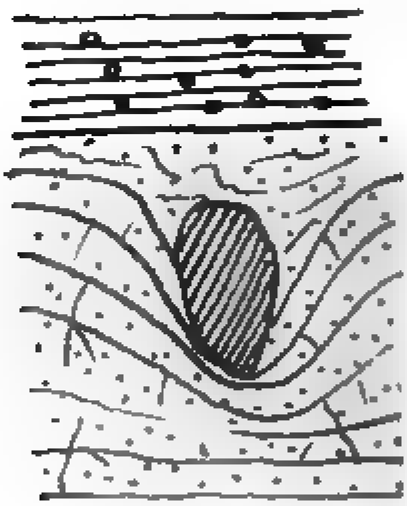
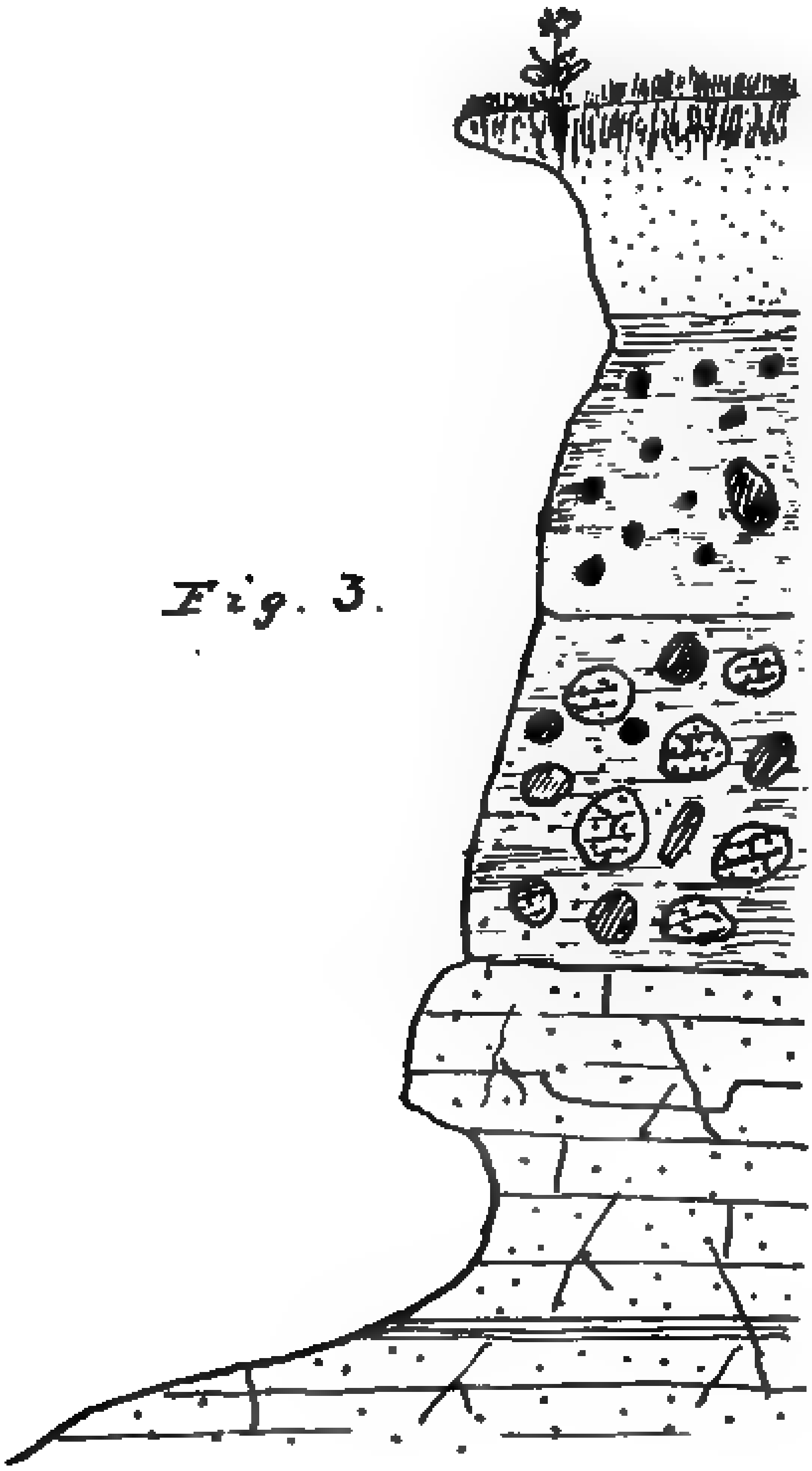


Fig. 3.



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In the next bay the clay thickens to 6 ft., and under the glacial deposits the rock is so much broken up that it is difficult to tell where the rock ends and the glacials begin.

In one place we have a section

2ft. soil
4ft. Boulder Clay
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About the middle of this second bay a landslip has recently occurred which hides the lower deposits, but a little further on a beautiful example of a "ground moraine" is seen. Fig. 3, Plate I. Here are angular

pieces of sandstone, some over a foot in diameter, mixed up most intimately with gravel clay and northern erratics.

Near the end of the bay the same features are met with, but the clay is 10 ft. thick, and the rock is only just visible below.

Further on the cliffs are very much obscured by landslips and vegetation. The drift is occasionally seen resting on the sandstone, and the lower part is a stiff sandy "till," containing a few well scratched stones, and it shades off into the more stony and more plastic clay above.

A peaty sand overlies the clay, and its base forms the line of drainage from the adjacent fields.

We have now reached a point just beyond the second bay. From this place the cliffs continue in a gentle curve, and decrease in height as we near the Rifle Butts. The rock is not anywhere exposed at the base, and the clay is overlaid by 2 ft. to 4 ft. of dark brown sand, highly ferruginous and without pebbles.

Landslips have obscured the face of the cliffs to a great extent, and it is only here and there we can get a clean section.

From the Rifle Butts to Withen Lane only the sand is seen, but Boulder Clay is exposed on the shore.

Beyond Withen Lane towards Decoy Marsh the cliffs are more lofty. They consist of Boulder Clay and "till," with numerous erratics and pockets of yellow sand. The surface consists of sand similar to that west of Withen Lane, but it contains pebbles.

A careful search along the cliffs did not yield any shells.

The cliffs are rapidly receding, and fresh features are exposed from day to day.

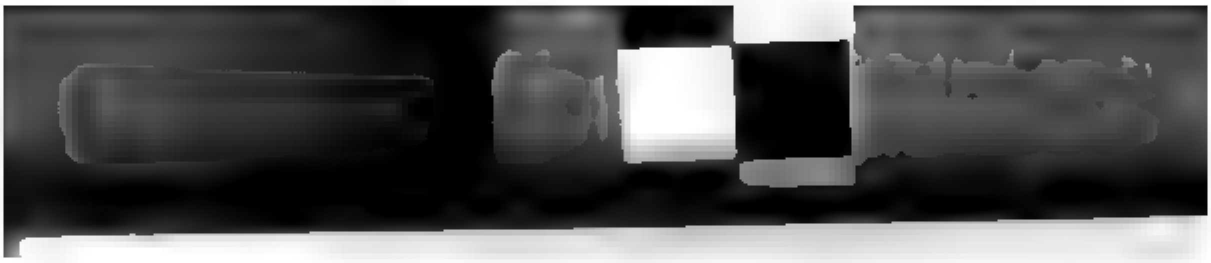

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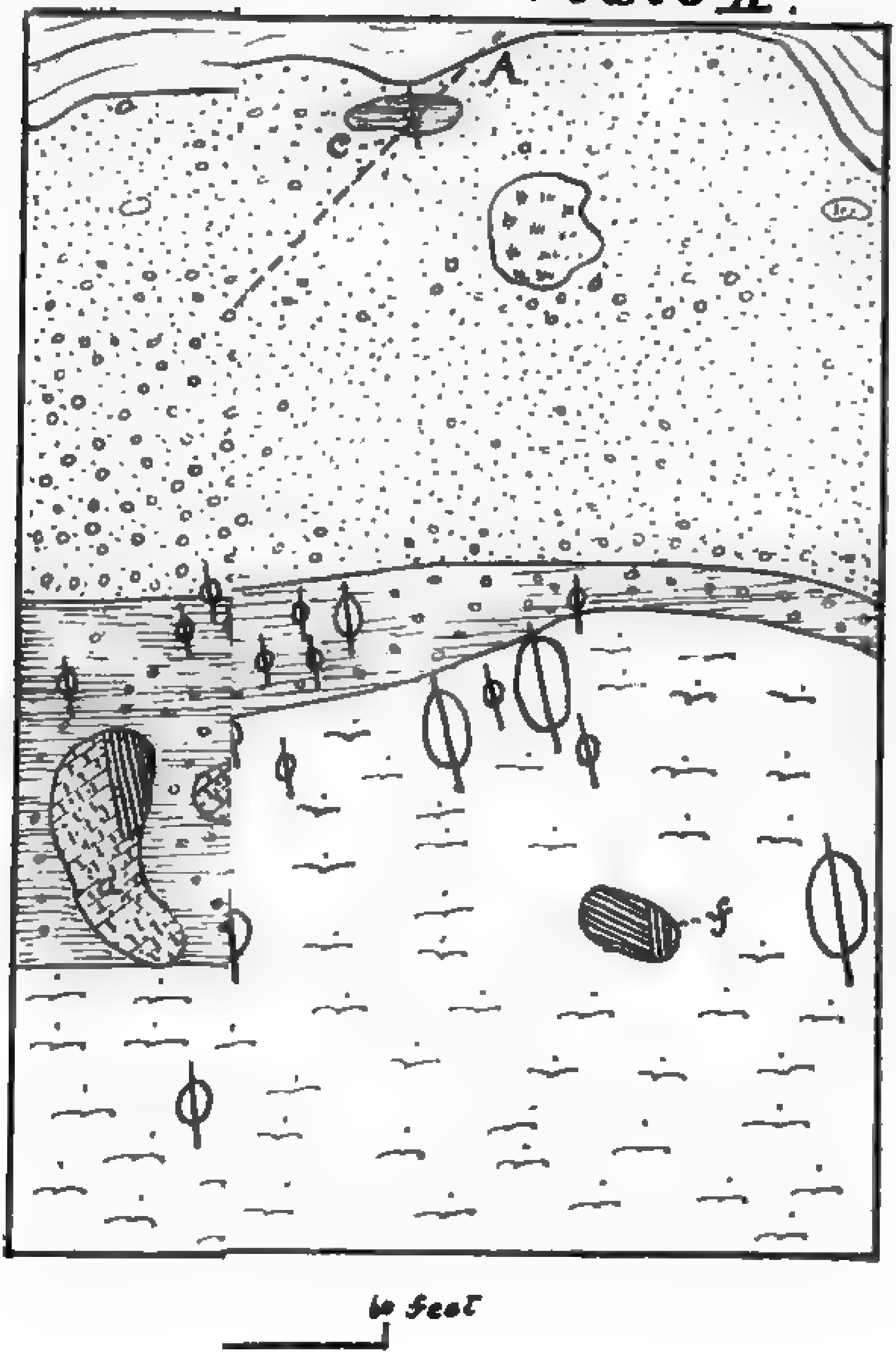
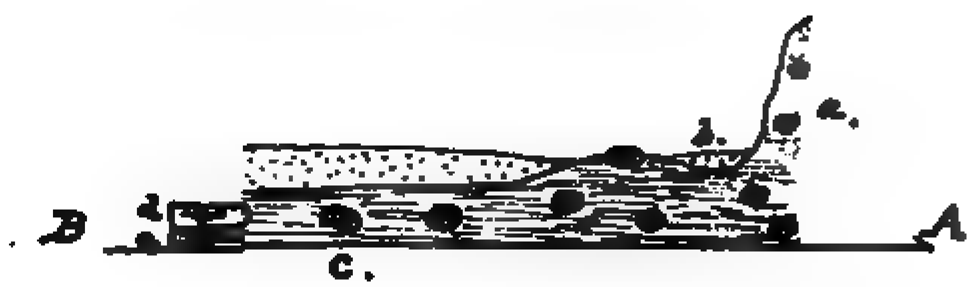
Plate II.





THE SHORE consists of a gently sloping platform, which terminates in a deep channel riverwards.

From the Lighthouse to the Perch (which marks the channel leading up to Withen Lane End) sandstone is exposed in irregular bosses. The hollows are filled in with Boulder Clay. Beyond the Perch no sandstone is seen, and the platform consists of clay.

The river action covers both the sandstone and clay in places with silt and sand. The areas so covered vary almost with every tide.

After some recent spring tides an area was swept clear opposite the Perch, which revealed an extensive striated surface on the rock. Figs. 4 and 5, Plate II.

Five separate patches were seen. Some of these have since been covered, and others have been laid bare.

Other bosses nearer the Lighthouse are planed as if by glacial action, but no actual striæ remain.

The striæ run 45° W. of N., and are on the land side of the boss in each case. The surface of the shore slopes riverwards at an angle of 5° *

The grooves are unusually wide for our district, and give the surfaces a fluted appearance. Some measure 2½ in. across and 1 in. deep. The underlying rock is very soft and crumbly, and that may account for the deep and wide scorings.

The surface of the rock dips towards the cliff under a bed of Boulder Clay, thickly packed with boulders. The surface of the clay is a plane coincident with that of the striated rock surface. The boulders enclosed just reach the surface without projecting; they have their long axes parallel, and are striated axially in a direction of 45° W. of N.

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* Obscure markings in the same direction are seen on the rock which forms the foundation for the Perch.

Out of 50 or 60 examples, only two small boulders were found which did not conform to this rule.*

Nearer the cliffs the Boulder Clay surface is hidden by sand, but considerable patches show through and present the same features as the main mass.

Numerous large boulders are seen in the silt beyond the rock, and with one or two exceptions they are oriented and striated like the others. One of the exceptions has its axis nearly E. and W., and is striated in that direction, but these striations are crossed by others at 45° W. of N.

We have here direct evidence that the agent which planed and striated the rock also, *at the same time*, planed and striated the boulders lying in the clay. This evidence also at once disproves the theory that an interval took place between the striation of rock surfaces and the deposition of the clay.

It has been suggested that such a period elapsed, in order to explain the absence of striated surfaces over certain areas. It will be noticed, however, that in about thirty recorded instances occurring near Liverpool, they always occur on hard rock—those on the Trias almost without exception being found on the Keuper Basement Beds, or the Pebble Beds of the Bunter.

BOULDERS.—Lying on the shore are a great number of large boulders. Over 200 have been recorded measuring more that 12 in. in diameter. A full list is given in the Twentieth Report of the Erratic Blocks Committee, British Association, 1892.

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* The late Mr. D. Mackintosh, F.G.S., has described a similar "striated pavement" (not associated with striated rock) at Dawpool. Q.J.G.S., 1879, p. 434.

Where the boulders have obviously not been moved the directions of the longer axes have been carefully determined.

It has thus been made clear that there is a gradual Easting in the direction of the Axes and striations as we approach Runcorn Gap.

In connection with this it should be noted that the striated surfaces described by Mr. A. Strachan, F.G.S., at Appleton, Farnworth, and Runcorn, also shew the same Easting.

Whatever the agent its direction of movement was profoundly influenced by the contours of the surrounding land.

The boulders are present in the following proportions:—

Lake District rocks	64·9	per cent.
Scotch „	26·2	„
Local „	1·5	„
Silurian Grits, and others of doubtful origin	7·4	„
	100·0	„

Among the smaller erratics we find Flints, and three specimens of the Ailsa Craig Eurite have been found near the lighthouse.

We are now in a position to review the whole shore from Liverpool to Decoy Marsh, a distance of about 15 miles.

Almost every available boulder has been recorded, and in so exhaustive a list negative evidence is as valuable as positive.

388 large boulders have been reported.

Comparing the Liverpool to Hale section with the Hale to Decoy Marsh section, we find in the latter an increase of 22 per cent. of Lake District rocks, and a decrease of 12 per cent. of Scotch.

It has been shown that these when *in situ* have an orderly arrangement, which corresponds with the direction of the striæ on the rock where exposed.

Two "striated pavements" have been described, one at Garston and another at Hale, showing that the clay itself was overridden by ice, and planed and striated like ordinary rock surfaces.

The evidence of direction of transport furnished by the boulders and striæ is that the erratics have come from a source north-west of the place we find them, and although there are characteristic rocks found to the north, and which are found as boulders further east, none of these have been seen on the Mersey shore in the district under consideration.

The change in direction of the striæ at Hale and Runcorn points to a cleavage on Weston Point, one branch going eastwards up the Mersey Valley and the other going south-east up the Weaver Valley.

It is significant that up both these valleys, so-called "pre-glacial" valleys, have been described.

With some diffidence we venture to suggest that these may be the expression of the ice movement along the valleys, and anyone acquainted with the scooping power of ice when cleft on a hill, will readily appreciate the fact. The deep gorge in front of Edinburgh Castle is a classical example of this action, and we have others in our own neighbourhood.

In these pre-glacial valleys the glacials are found to the very bottom. No river or other deposits separate the rock from the drift. If these ever existed they must have been scooped out by something which moulded itself perfectly in the hollows. It is our opinion that all the facts stated in the paper are consistent with the

passage of a great sheet of land ice over the district, and we have observed nothing which would tend to support the theory that the deposits were formed during a period of great submergence.

EXPLANATION OF PLATES.

PLATE I.:—

Fig. 1.—Boulder embedded in apparently undisturbed sandstone, Boulder Clay overlying.

Fig. 2.—Boulder embedded in sandstone, marl bands in the latter having been dragged down.

Fig. 3.—Section of cliff showing ground moraine.

PLATE II.:—

Fig. 1.—Plan of Shore.

(*a*) Cliffs.

(*b*) River Sand.

(*c*) Boulder Clay, with erratics in situ.

(*d*) Pebble Beds of Bunter, the lines showing the striæ.

(*e*) River Silt.

Fig. 2.—Section through A B on Fig. 1.

a, *b*, *c*, *d*, and *e* as in Fig. 1.

(\$) Striæ in Section.

SOME OBSERVATIONS ON MOUNTAIN DEBRIS.

By LINNÆUS CUMMING, M.A.

A NOTE was appended by the present writer to a paper on "Mud Avalanches," by Mr. E. Dickson, which was published in the Proceedings of this Society for the last session. He there recorded the observation of mud cones or fans on the Stelvio Pass, observed by him during the autumn of 1891. His next holiday tour, in August, 1892, took him to the Dauphiné district, in the south-east of France, where he was fairly startled to observe those débris fans on a scale not before dreamt of. On pursuing the course of the Veneon torrent above La Bérarde, towards the Glacier del Pilate, the road lay over a series of such fans, every gully in the nearly

perpendicular rock face containing the apex of one such fan, which stretched out across the valley, and at its lower end was abruptly cut into by the torrent. The

accompanying drawing shows one such fan mass, which chanced to be most accessible from head quarters. Measurements were taken as carefully as the very rough nature of the ground permitted. The length of the fan from the apex to the stream in a direct line is 375 yards, while the width C D along the base, following the foot-path, is 780 yards. The slope of the fan could be only taken roughly on account of the enormous rock masses which encumbered the surface, but by observation at A it was 19°, and at B it was but 18°.

Over the surface of the fan was a stream from A to somewhere to the right of B, which carried off some of the drainage from the gully, but skirting the edge of the fan, near both C and D, were springs flowing from it, showing that a large quantity of water percolated through the débris composing the cone.

From C to D the stream had cut off the lower end of the fan, and gave the section, of which some idea may be gained from the diagram. The bank giving the section had an inclination of 33° at E F, and the distance measured from the top of the fan to the level of the stream was 42 feet.

The débris fan was composed of rough sand of no great coherence, easily broken up by the axe, and containing rock masses of all sizes—from the size of a cottage to the smallest fragments (some of which were exhibited to illustrate the great variety of rock which existed in the mass). Except in the stream channel there were no rocks showing traces of water action, no rounded or water-rolled pebbles; all were angular, with at most the sharp angles slightly rubbed down, and only in this respect different from the débris seen in a moraine. The surface was entirely rock strewn, with none but the scantiest traces of vegetation.

On either side of the neck of the fan, near A, was the slope of reddish earth clothed with vegetation, formed by the natural decay of the cliffs above, and lying at a much steeper angle—27° or 28° as against 19° on the fan. During several ascents in the higher mountain regions the source of such a vast accumulation of débris was easily traced.

The district, as far as our present purpose goes, is a mass of granite and gneiss in great variety of form and texture, but without mixture of any other rock. The rock splits up with remarkable freedom under the action of weather, leaving exceedingly steep mountain valleys and peaks, rising to 12,000 feet, which are only accessible by hard climbing, hands and feet being constantly in requisition. The Veneon Valley is a steep-sided valley ploughed out by the Veneon torrent, probably aided not long since by glacial action. The upland valleys are wider, and in their upper portions are still occupied by snow-fields and glaciers. These valleys are covered to various depths by stones, sand, and mud, derived from the glaciers and snow-fields, and often saturated by water, which flows about over the ground and not in confined channels. This material lies in a steeply sloping bed of rock, which where exposed shows upward sloping "roches moutonnées." The foot-hold, where the débris is but a few inches thick, is very insecure, slipping back as attempts were made to surmount it, and needing great caution to traverse.

Such material, given a large supply of water from the spring melting of snows, would doubtless compose just such a viscous mass, as had been observed on the Stelvio, and would move bodily forward, carrying with it loose boulders, and finding its way by gullies into the steep-sided valleys below. The last excursion in the

district was an ascent of the Aiguille de la Bérarde, a beautiful peak on the opposite side of the Veneon Valley from the débris-fan, above described. At one point of the ascent there was a view directly into the gully and over the uplands, immediately above it, with their débris and true glacier moraines of large size, formed by the extensive glaciers of Les Ecrins, which tower above it.

On examining the valley, both above and below La Bérarde, evidences occurred at every step of such accumulations, which must in the course of time have filled up the valley to a considerable depth, as well as have furnished material to the Veneon torrent—such material, by the agency of the stream, being constantly transported to lower and lower levels.

So much is fact. The author would now invite the assistance of geologist members of this Society, to assist him in the sifting of some few speculations, which these observations suggested.

In the first place, is it possible that some accumulations of such rough débris as has been described, and which is found in our own mountain valleys, may be due to the causes indicated, rather than to direct transport by ice—which is, perhaps, the generally accepted view? There can be no doubt that the rocks of the Veneon Valley would, if uncovered, show plentiful traces of ice action. That the whole valley was once the site of an extensive glacier, no one can doubt. At the same time we should be vastly mistaken, were we to gauge the extent of the moraines of that glacier by the amount of material, more or less resembling moraine, which is now found there.

In the second place, is it possible that these observations point to the existence under the surface of

every turbid river of a mud-paste, holding stones and carrying them along with its current? It would help us to understand the transport of large blocks of stone, which would be relatively less heavy when supported in a mud-paste instead of in turbid water alone. Material carried in this way would get in its progress more or less rounded, or as it is called "water-worn," and would form exactly the kind of deposit found in old lakes or other wide valley-areas, which have been filled up to a nearly level surface with stones and mud, the very levelness of the surface giving the appearance of the gradual settling down of a plastic or viscous mass.

The author observed such a surface at the head of the Justedal Valley in Norway some years ago. While walking along the lateral moraine, from the Lodals Brœ, there came into view a wide valley, filled up to a nearly horizontal plane, and intersected by innumerable streamlets, into which the drainage from the glacier was divided.

At first he thought this observation gave a clue to the vast accumulations which occur in the Norwegian valley, which are still perhaps unsolved riddles. Here, however, was a level surface in act of making, and ere long the drainage would be restricted again into one or two main channels, and would begin to cut down through the detritus which had only just been formed, and we should have another bank of mountain débris, angular and rounded and of all sizes, capped by a level terrace. Is it worth the while of geologists to consider whether these mud torrents have played an important part in bringing about these changes?

Lastly, it has often been noticed that rivers run between raised banks of their own making, the

immediate bank of the stream being often raised several feet above the surrounding plain. In the case of the Mississippi, Sir Chas. Lyell explains these banks by the annual overflowing of the river. He says:—

"The cause of the uniform upward slope of the river bank, above the adjoining alluvial plain, is this—When the waters charged with sediment pass over the banks in the flood season, their velocity is checked among the herbage and reeds, and they throw down at once the coarser and more sandy matter with which they are charged. But the fine particles of mud are carried farther on, so that at the distance of two miles a thin film of fine clay only subsides, forming a stiff, unctuous, black soil, which gradually envelopes the base of trees growing on the borders of the swamps."—(Lyell's Principles of Geology, vol. i., p. 444).

Many streams, however, in mountain regions have banks of loose stones raised many feet above the level of the plain, where there is no vegetation to obstruct the river sediment. This has long been one of the puzzles for which the writer has not yet arrived at a satisfactory solution, nor does he attach much importance to the suggestion which follows. It is this:—Given the banks of the stream brought to the soft pasty condition, by the presence of super-abundance of water; is it possible that the constant impact of the stream and the detritus it carries on the softened banks could exert such pressure as to raise up mounds on either side parallel to the stream? Just such banks would be raised in a plastic body like clay, if the finger were gently pressed into it, and drawn through it along a line. In the Veneon Valley, on the highest part of one of the mud fans described above, runs a channel, in which the drainage

from the gully at the head of the fan is carried away, and which is guarded by banks of loose material exactly similar to those so often seen elsewhere. Now in such a position, lying at the very highest part of the cone-like mass, it could not be imagined that the deposit of mud banks was made during the overflow, which would have at once spread over the whole sloping surface.

ON SOME CONDITIONS EXISTING DURING THE FORMATION OF THE OLDER CARBONIFEROUS ROCKS.

By Charles Ricketts, M.D., F.G.S.

By a careful study of the different series of Lower Carboniferous rocks, it is hoped that it may be possible to determine, to some extent, the conditions under which they were formed. But it must be understood that the remarks I am about to make apply almost exclusively to the north-western district of England.

Subsequent to the formation of the Old Red Sandstone a long period elapsed, during which, if any strata had been deposited in the district referred to, the whole had been subsequently removed, as well as a large amount of Silurian and older rocks, in which numerous brooks and rivers had excavated for themselves channels.

In different localities at or near the bottom of these valleys are beds of pebbles, sand, and clay, which form the basement to the Carboniferous Limestone wherever they occur. These were formerly wrongly referred to as "Old Red Sandstone."

The locality best known to our members, where these beds occur, is situated at the base of the Eglwyseg escarpment at Llangollen. The strata as described by Mr. Morton "consist of dark red sandstone, with some brecciated conglomerates interstratified with it, and the included fragments seem to have been derived from the Silurian rocks."* The pebbles are deeply stained with oxide of iron. The beds are not visible *in situ*, but on one occasion I saw them dipping beneath the escarpment at or about the same angle and direction as the limestone itself; this extended westward would cause both the basement beds and the base of the limestone to abut against hills of Upper Silurian shales and slate.

Another well-known example of these basement beds occurs near Kirkby Lonsdale, referred to frequently by Professor John Phillips, of Oxford, as Old Red Sandstone;† but he remarks that "it is chiefly on the evidence of intermediate geographical position that these conglomerates and clay-beds were so admitted." He also states that "they are confined to valleys in the slate formation, and that it is a deposit caused by a very limited current, which was perhaps confined to what is now the track of the Lune." In this and in other instances their formation must be referred to deposits brought by streams of no great size and left on the bottom of the valleys, when the force of the current, impeded near their mouths by meeting the waters of the sea, could not carry these materials to a greater distance; the land consequently became more and more

* The Carboniferous Limestone of North Wales, page 26.

† Geol. Trans., 2 Series, vol. iii. Geology of Yorkshire, Mountain Limestone, page 13. Mountains and Sea Coast of Yorkshire, page 173.

depressed, owing, it is presumed, to the weight of these and other accumulations deposited on the bed of the sea in the near neighbourhood.

During the excursion of our Society to Settle in 1891, an example of similar conglomerates was seen at the base of the limestone in Beecroft Quarry, near the Railway Station at Horton in Ribblesdale, where a small stream, which flows into the Ribble, issues from beneath the base of the Carboniferous Limestone; the position of these pebbles indicates that the little stream which now flows over them is the direct successor of a stream which flowed at the period of the deposition of the Carboniferous Limestone.

The general character of the basement beds, near Shap Wells, is a red sandstone, having a black shale intervening between it and the limestone. Wastdale Beck, which has its rise in Wastdale Pike, and partly in the Granite mass, passes near the Hotel, over a breccia, formed of Silurian pebbles and flesh coloured Felspar. According to Professor H. A. Nicholson* a conglomerate containing an occasional crystal of flesh coloured Felspar occurs in the valley of the Birkbeck. These different localities are situated on streams, which joining together now form a tributary to the river Lune, as they likewise did in pre-carboniferous times.

At Shap Abbey, where the basement beds of Carboniferous Limestone are exposed, the river Lowther runs in a northerly direction, through a gorge formed on its western side by Lower Silurian Strata, and on its eastern by an escarpment of horizontal beds of Limestone. The lower six or eight feet is a fine gravel, composed of angular fragments, all of which may have been derived from the Silurian rocks of the neighbour-

* Geology of Cumberland, page 74.

hood. Though covered by beds of limestone they remain entirely unconsolidated.

From these instances, it appears that the streams by which these basement beds were accumulated must have been of moderate size, derived from areas approximately the same as those which supply streams in the same valleys where re-excavated at the present time, and have been in each case restricted to the same water slopes, but surrounded by sea, forming promontories or islands.

If the course of the River Lowther was roughly indicated in pre-carboniferous times, it is reasonable to conclude that other dales or valleys were also being formed at the same time, such as of Swindale, of Hawes Water, of Ullswater, and many others. In the instances which have been under consideration, the pebbles, sands, and clays have been derived entirely from local sources, and have not been cemented together by calcareous or other material; they are situated in the *bottoms* of valleys formed in older rocks, but do not extend up their flanks. They are overlaid by limestone—the Carboniferous Limestone—impure in the lower beds, afterwards becoming white and almost free from other materials.

The occurrence of the limestone forms a great and abrupt alteration in the character of the deposits, but no great physical change has taken place to cause it. The process of submergence in operation previously still progressed; the sea was therefore enabled to flow further up the different valleys in the bottoms of which these pebbles, &c., were left, when the force or volume of river water was insufficient to carry them seaward.

The condition of the base of the Carboniferous Limestone varies greatly. In North Wales its junction with the older rocks is not often seen, being covered with

talus. At Llangollen and at Shap, where the basement conglomerate has been previously deposited, the lowest beds are very impure, consisting greatly of mud and sand, as well as Carbonate of Lime.

On the south side of the river Dee, opposite Trevor Station, and at Brackenbottom, near Horton, in Ribblesdale, it is, on dissolving away the lime by acid, found to consist, in a large proportion of small fragments, such as may be designated as grit, derived from rocks similar to that on which it rests.

The general condition of the base of the Carboniferous Limestone in the Ingleborough district, is a calcareous conglomerate, containing a very large proportion of Silurian fragments, probably derived from rocks in the near vicinity. They coincide with the description given by Mr. A. J. Jukes-Browne* as occurring in Co. Dublin, and consist of blocks from Silurian rocks cemented together by Carboniferous Limestone; quoting his uncle, Professor J. Beete Jukes, he observes, "this is evidently a portion of the very beach, or margin, of the Carboniferous sea in which the fallen blocks and shingle from the wasting land above were enveloped in the calcareous deposits of the Carboniferous period." Large pieces, three feet and more in length, may be seen at Norber Crag, near Austwick; large blocks also occur in the stream at Thornton Force, Ingleton. Generally the fragments decrease in size the higher they are situated in the escarpment.

An exception to the general condition occurs at Beecroft Quarry; the lowest beds of limestone do not contain pebbles, but are black in colour, due to carbon in an impalpable powder, suggestive of its being a deposit from peaty water; this is rendered probable

* Building of the British Isles, page 73.

from a band of coal, about 8 in. thick, resting on the uppermost layer of black limestone without any indication of denudation or weathering of the surface of the limestone. Subsequently the limestone becomes grey, and in the upper beds white.

Near the entrance to the tunnel on the Holyhead Railway, at Trefdraeth, the base of the Carboniferous Limestone is formed of a conglomerate of rounded quartz pebbles; they were not derived from the rocks against or upon which they rest; they can with more probability be referred to what have been called "quartz knobs," one of which forms the hill on which the windmill at Llangefni stands. Pebbles of a quartz similar to that of Windmill Hill, and rounded as at the Railway Tunnel, enter greatly into the composition of the base of the Carboniferous Limestone, as seen in a quarry on the opposite side of the road.

The thickness of the limestone varies considerably, caused greatly by the irregularity of the surface on which it was deposited, partly also by subsidence taking place to a greater extent in some places than in others. In Derbyshire the total thickness of the strata shewn is 1,580 feet, without reaching the bottom.* Mr. Morton† calculates the thickness of the Eglwyseg rocks, Llangollen, at 1,000 to 1,200 feet; but within four miles (at Fron) the surface of Upper Silurian, on which it rests, must have been on the flanks of an escarpment 873 feet above that of the former, for that amount of the lower beds is missing.

Resting on Silurian strata the limestone extends southward, by Chirk to Llanymynech, but in consequence of the unevenness of the basement, varies in thickness,

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* Mem. Geol. Survey, Derbyshire, page 18.

† Carboniferous Limestone of North Wales, page 29.

though it is always moderate compared with the Eglwyseg escarpment. The present is not the original limit, but it could not have extended southward very much farther, for at Pontesbury and south of Shrewsbury, the Stiper stones and Longmynd rocks are covered by Coal-measures, no limestone or other strata intervening. The Carboniferous Limestone also terminates at Little Wenlock, being there about 20 feet thick, likewise in Leicestershire, near Charnwood Forest, in each case indicating the shore margin of the Carboniferous sea; Coal-measure strata being deposited on older rocks. Professor Jukes, alluding to the fact, remarks "that there is a band of country running east and west across England, from Leicestershire, through Warwickshire, South Staffordshire, into Montgomeryshire, along which they are equally deficient;"* it formed "a narrow promontary, or an island, or a group of closely connected islands, running in an east and west line across the district."†

The chief impurities occurring in the lower Carboniferous Limestone are of local origin, derived from the land in the neighbourhood of the deposit; the calcareous ingredients had their source in a far distant locality. Whether it is considered to have been precipitated from water holding lime in solution, due to the liberation of the excess of Carbonic Acid, or derived from the exuviæ of marine organisms, or from both combined, a constant renewal of the lime must have occurred, the source being at a distance so considerable that all insoluble particles had been precipitated near the mouth of a great river, comparable to the Mississippi or the Ganges, carrying away the drainage of a continental area. The

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* South Staffordshire Coalfield, 2nd ed., page xii.

† Page xiii.

thickness of the accumulation was greatly dependent on the contour of the ground upon which the Carboniferous strata were laid down. There are reasons for inferring that the depth of water was not so great, but that its bed was to some extent affected by the action of the waves. Detached fragments of the stems of Eucrinites, often of single joints only, are very common, but the Calyx is seldom met with. The occurrence of an Echinus (sea urchin) is by no means rare, but represented by portions only, such as ambulacral plates or the spines. The shells of mollusks are often separate, but with no appearance of having been subjected to rubbing, and very rarely to fracture.

An indication of comparatively shallow water is the existence of thin beds of Coal, interstratified with the limestone. Some are similar to the one at Horton, in Ribblesdale, already referred to, in which there exists no appearance of erosion or weathering of the surface on which it rests. The same state occurs in the middle example of a land surface at Ingleton Quarry, also at Denbigh and Nantclwyd.

In some cases the newly-formed surface of limestone is eroded, forming hollows and pits, subsequently filled with mud or shale, on which vegetation has flourished to an extent sufficient to form thin beds or films of coal; these being afterwards depressed, great thicknesses of limestone were formed above them. The best known example occurs in the extensive quarry at Ingleton, but, as quarrying progressed, the exposure has become more and more deteriorated. When first visited (say about 25 years ago) the surface of a bed of limestone was eroded and hollows formed, in the bottoms of which were grey mud and angular fragments of Carboniferous Limestone overlaid, for a thickness of five feet, by black

shale, on which rested a bed of Coal a foot thick, which was again overlaid by limestone.

In the third example of a land surface occurring at Ingleton, the bed of Limestone is formed pretty regularly into basin-shaped hollows, about a yard in width, the surfaces being weathered white and powdery, and the fossils standing in relief; the hollowed space is filled with grey mud, with much Iron Pyrites; over which is a thin bed of coaly material.

At Combsdale, near Stony Middleton, between four and five miles N.N.E. of Bakewell, there extended the whole length of the quarry (about 60 yards), a weathered surface of thick bedded limestone, covered with a layer of clay, and also a bed of coal one inch thick; over it lies a dark brown shelly mud, and above that again, thin bedded cherty limestone. At the further end of the quarry the erosion has formed three hollows, from 18 inches to 2 feet in depth, filled with grey clay, in which were limestone fragments. This section is referred to in Memoirs of Geological Survey, North Derbyshire, page 25, but the conditions cannot be realised from the description. I have described in our Proceedings for 1880, an instance of a land surface having a thin film of carbonaceous material, seen many years ago where Deepdale joins Ashwooddale, near Buxton.

A land surface is indicated by the weathered condition of the Limestone on the left-hand side of the road from Millersdale Station to Tideswell, over which Volcanic mud was spread, remarkable for its upper portion being formed into prisms caused by an overflow of Toadstone or Lava.

In a small roadside quarry at Henridden, three miles N.E. of Carnforth, there is a thin bed of Coal interstratified with the limestone. When first seen, the coal for a

considerable portion of the exposure, rested directly on the limestone, but at another part there intervened a thin bed of grey clay, varying in thickness up to an inch or more, filling up pits and channels, and extending downwards through crevices, formed and enlarged by weathering, in the stratum below.

In a quarry at Nannerch, Flintshire, situated opposite the Railway Station, there is a somewhat similar example in the lower portion of the Carboniferous Limestone. A stratum of limestone, fissured and weathered, has been covered by a thin deposit of clay, which also fills up the intervals in the joints, and upon which clay a film of Coal rests.

It should be remarked that in most, if not all, of these instances of land surfaces, there exist indications of minute fissures in the limestone; these have been filled with Calcite. In some cases the presence of these cracks has influenced the formation of channels, by weathering; the thin films of Calcite projecting at the bottom of the weathered channels. Larger joints at Ingleton, Henridden, Deepdale, and Tideswelldale have their sides affected as if water had overflowed, or trickled down from the upper surface of the limestone.

As the lately deposited calcareous strata were in these instances raised above the sea level so as to permit the erosion of the surfaces and the growth of plants, and this occurred in different localities and at different periods, it is more than probable that the general depth of the Carboniferous sea was comparatively shallow, that in fact the subsidence did not much exceed the amount deposited on its bed.

In the upper beds of Carboniferous Limestone there exist evidences premonitary of an alteration in the character

of the deposit; the colour of the limestone is altered to a greater or less degree of blackness. This may be due to an addition to, or a change in, the constituents of the sea water; as if there were mixed with it a large quantity of moss water, derived from swampy vegetation in connection with the river or rivers emptying themselves into this sea. The amount of Carbonaceous matter incorporated with the limestone is sometimes, as at Ashford, near Bakewell, so great that it is quarried for black marble, and used for ornamental furniture.

Another change also—the precursor of one still greater (the series known as Yoredale)—is the large quantity of Silica contained in the limestone, forming nodules, and bands, and aggregating around organisms. It occurs very generally in the upper strata throughout the whole district; at Bakewell it is quarried for use in the Staffordshire potteries as mills for grinding calcined flints, used in the manufacture of porcelain.

To the presence of this Silica or chert in the upper limestone may be referred the formation of quartz crystals, combined with Calcite, in vesicular cavities in the Toadstone, at Monsaldale, Bakewell, and Shaklow. It does not, so far as observed, occur in North Derbyshire, in Volcanic rocks, prior to the Cherty limestone.

Subsequent to the Cherty Limestone, and lying comformably upon it, are the beds of the Yoredale series; a succession consisting of shales, sandstone, and grit, separating beds of limestone; these are many times repeated. Occasionally there occur thin beds of Coal which have sometimes been worked, but only for local consumption. Under what conditions may we suppose that these great changes have taken place?

There is a liability for rivers to change the direction of their course in passing through alluvial plains or deltas, where the recently deposited materials, being unconsolidated, are readily washed away by floods and other causes. The most notable instance is that of the Hoang Ho, the waters of which, previous to 1852, passed into the Yellow Sea, but about that time so altered its course that it emptied itself into the Gulf of Pee-che-lee, a distance of 640 miles along the coast line. This is an extreme example, but it proves the possibility of great changes taking place in the course of a river such as would entirely alter the character of its deposits. A change in the deltal extremities of other rivers is recorded, for instance that of the Ganges and Brahmapootra, which are known to have altered within a very short period, and Lyell remarks that on the sea coast in the Bay of Bengal there are eight great openings, each of which has evidently at some ancient period served in its turn as the principal channel of discharge. Applying these principles to explain the changes in the character of the deposits constituting the Yoredale series, there will be sufficient to account for the great variations which have taken place. If the situation and direction of the main current changed there must have been a change likewise in the quality of the ingredients deposited in different localities. The coarser and heavier sand and grit would have rested near the mouth of the river, whilst the finer mud was carried further seaward, or to a distance on either side, whilst at a still greater distance the limestone and also the chert (as at Holywell and Leyburn, in Wensleydale), have gradually been deposited.

The gradual and continual deposition of the debris derived from the erosion of continental areas could only take place, because there was at the same time a gradual

and continued depression in the locality where these materials were being laid down. Whilst this fact is constantly recognised and universally referred to as occurring not only in the carboniferous, but in every formation from the oldest to that now in progress, there appears the greatest reluctance to admit that the one may be dependent on the other as cause and effect.

NOTE ON SECTION AT SKILLAW CLOUGH, NEAR PARBOLD.

By E. Dickson, F.G.S.

A brief description of this section is given in the Survey Memoir of the "Country in the neighbourhood of Wigan," and also in the "Geology of the Country around Liverpool," by Mr. G. H. Morton, F.G.S., p. 64.

The Clough is about equidistant from Hoscar Moss and Parbold Stations on the Southport and Wigan line, being about 1½ miles from either station. In the Survey Memoir regret is expressed that no fossils had been found in the Limestone, Marls, or Sandstone—strata of which the section consists, but from other evidence the conclusion is arrived at that the strata belong to the Permian. I am glad to be able to confirm this conclusion from the evidence of fossils found in these marls, and as fossiliferous strata in the neighbourhood of Liverpool are not abundant, I wish to draw attention to this section as adding one more to their number. Some months ago when visiting this section I found in the red

marls, about 10 feet below the limestone bed which forms its highest portion, an indistinct cast of what I thought was, and has since proved to be, a Schizodus. Since then I have carefully examined the red marls which underlie the limestone, and are of a thickness of about 30 feet, and found in them at least four horizons containing fossils in comparative abundance of a Permian type, the majority being indistinct, but many being casts in a very fair condition. In the Limestone, which is clearly a Magnesian Limestone, I have not as yet found any very distinct indication of fossils. Mr. P. Holland, F.I.C., a member of this Society, has very kindly analysed this limestone for me, and the following is a copy of his analysis:—

SiO_2	3.23	
$Al_2O_3 + T_1O_2$	0·84	
Fe_2O_3	0·93	
$FeCO_3$	9·15	
FeS_2	1·89	
MnO	0·87	
$CaSO_4$	0·18	
$CaCO_3$	57·10	
$MgCO_3$	24·15	
P_2O_5	—	
K_2O	0·28	
Na_2O	—	
Combined Water	1·25	
Carbonaceous matter not estimated	—	Sp. Gr. 2·875
	99·87	

I have also searched for fossils, but hitherto without success, in the beds of soft reddish sandstone which underlie the fossiliferous marls to a thickness of about 35 feet. Further up the stream which runs through the Clough are seen the grey or purple shales of the Millstone Grit. In the Survey Memoir above alluded to, it is stated that it is uncertain whether these

Permian Sandstones rest on or are faulted against the Millstone Grit. After careful examination I have arrived at the conclusion that the former rest unconformably on and are not faulted against the latter. The reasons for this conclusion and a list of the fossils found in the marls I hope to give to the Society in another Session, together with an account of the exposure of Permian strata in the neighbouring Bentley Brook.

REMARKS ON THE FORMATION OF CLAY.

By P. Holland, F.I.C., and E. Dickson, F.G.S.

In a paper that we had the honour of reading to this Society at its meeting in April, 1889 we remarked on the absence of clay in Alpine districts, an observation confirmed by others. Nowhere did we meet with a material having the physical and chemical character of the clays familiar to us in Great Britain, though it would be only natural to expect to find beds of clay in valleys where the geological formations and glaciated condition of the mountains are such as to favour the production and transportation of clay. In the paper alluded to true clay was defined as "hydrated silicate of aluminium," and a distinction was drawn between true clay and the extremely fine sand or mud suspended in water flowing from the tongues of glaciers, which fine mud in the case of the Aär and the Arve gives those streams their familiar milky appearance. To a very small extent, however, this milky appearance does really depend on the presence of clay, for on pouring off a portion of the supernatant fluid of a glacier water

acidifying, and filtering, the filtrate gave characteristic reactions for alumina. A *little* clay in a glacier stream is explained by the fact of the water from the melting ice washing away the decomposed aluminous minerals from the weathered surfaces and fissures of the rocks over which it flows.

In view of experiments to be made with a sand similar to that of a glacier torrent, a mixture of several sorts of rock, including granite, basalt, and diabase, was taken and finely powdered, and the resulting powder analysed. It gave the following figures after drying at 212° F.:—

SiO_2	66·98
Al_2O_3	11·45
Fe_2O_3	3·47
FeO	2·19
MnO	0·23
TiO_2	0·31
CaO	2·86
MgO	3·41
K_2O	3·18
Na_2O	3.30
CO_2	0·50
Combined Water	2·26
	100·14

The analysis, it will be observed, records 2·26 per cent. of water of constitution, water which is a component of most rock-forming minerals and is wholly unconnected with the mere moisture a rock may absorb from the air. We call attention to the combined water, for it has been observed that for two specimens of the same rock, the one quite sound and the other in course of decay, that the decayed rock contains the larger amount of combined water. Now, as the hydration of the alumino-ferric contents of the rock will be greater as the decay proceeds, the increase in the amount of combined water may be taken as an index of the extent

of the change when comparing two specimens of the same rock. In the case of highly felspathic rocks, the greater the hydration, the more will the fine matter removable from such rock by crushing and washing with water partake of the nature of clay.

Some experiments were made with the powdered mixture of rocks just mentioned, of which two are given. Some forty grammes or so was washed by elutriation, and the finer particles in suspension poured into a second vessel for subsidence. The sediment or fine mud fitly resembles what is found in a glacier torrent. It was collected and dried at 212° F. In most respects it was like the coarser powder whence it was derived. Mica particles were somewhat abundant, but there was a less total of silica than in the original powder, which was to be expected, as elutriation would remove some of the heavier quartz. The dried sediment on re-moistening with water was not plastic as clay is. Pellets made with it and contrasted with similar pellets of china clay had no cohesive character. It was not expected that clay would be at once formed in this way. The experiment had for its object a comparison of the plastic quality of a true clay with a fine mud, the product of potentially clay-forming rocks.

Clay, it would appear, may be described as mud, yet mud is not necessarily clay.

The main cause of the conversion of rock-forming minerals into clay is the long continued action of water. We may cite in this connexion some interesting experiments of H. Rose* on the chemical effect of water on minerals. Messrs. Rogers † too, in 1848, made similar observations, and noticed that a solution of carbonic acid in water had a marked action on the

* Annalen 82, p. 545. † American Journal of Science and Arts.

silicates of lime and magnesia; the action was more pronounced in the case of these silicates than in the case of felspar, and would in Messrs. Rogers' opinion account for the more rapid decomposition of rocks made up largely of hornblende and other magnesian minerals of like character.

The question arises, how does the initial action of the water and carbonic acid set in? In rocks in which gypsum or calcite is a noticeable component, the commencement of decay may be traced to the solvent action of water on these minerals, and in proportion as they are removed so will the rock become more permeable to water. We give in a later part of the paper an example of this action in connection with a diabase intrusion occurring in a granite quarry in Jersey. Calcic minerals may, however, be entirely absent from a rock, as is the case with many varieties of granite, and yet the rock will decompose and in time yield clay. The familiar "rusting" of many kinds of rock is evidence of the change induced by the combined action of air and water on the ferrous minerals composing the rock. It would appear probable that the ferrous minerals—by which is meant minerals containing iron as ferrous silicate—are split up into hydrated ferric oxide,—the red oxide,—and silicic acid; thus a 'caries' of the stone is set up. Something may be said for this theory, which will doubtless receive confirmation can it be shown that rocks rich in ferrous minerals yield to atmospheric influence more readily than do rocks in which such minerals are but sparingly represented. Bischof deals with the decomposition of silicates by water containing in solution lime and oxide of iron, and refers to some interesting pseudomorphs having the form of felspar crystals which occur in a red

porphyry from Ilmenau.* These reddish brown pseudomorphs evolved carbonic acid when treated with hydrochloric acid, and the solution was found to contain the chlorides of calcium and iron. When the action of the hydrochloric acid had ceased there remained a skeleton form of the original felspar crystal. Now, as orthoclase felspar is devoid of lime and oxide of iron, the inference will be that the conversion of the orthoclase crystal into the pseudomorph is directly attributable to the action of water holding the above bases in solution, which bases had in process of time displaced those natural to the felspar, viz.:—alumina and potash. The observation is valuable, for it shows how fundamental a change in an important rock-forming mineral can be caused by very simple agency. The reaction between acid carbonate of lime, and silicates of potash can be followed in the laboratory, and the evidence such experiments afford will support Bischof's explanation of the genesis of the pseudomorph he describes. In connection with this question we made the following experiment:—A portion of the elutriated rock sample of which the analysis has been given, was acted upon by carbonic acid and water under pressure for twelve months. The solid matter was at the end of that time removed by filtration, and the filtrate examined. It contained lime, magnesia, and oxide of iron. A trace of potash could be detected with the spectroscope. We are unable to give data as to the amount of matter dissolved; the reactions for lime and iron were very distinct, however. Such an experiment merely confirms the observations of earlier investigators, viz., that carbonic acid has a solvent action on rock-forming minerals, and must obviously be a factor in promoting the decay of rocks generally.

* G. Crasso, Annalen xlix. 381.

We will now pass on to some observations in the above connection on specimens collected in Jersey in the summer of 1891. On the opposite faces of a disused granite quarry, south of Fort Regent, above St. Helier, and continuous along its floor, is an intrusive dyke of diabase, about 14 inches wide, running nearly east and west. On the eastern face of the quarry, at a point near the present land surface some 40ft. above the floor of the quarry, the diabase was quite decomposed and altered to a brown ochreous material, having some plasticity when wet. On examination *in situ* it was seen to be fissured in rectangular directions, so that it was easy to remove portions having a cubical form. The material dried at 212° F., feels light in the hand, and has a Sp. Gr. of 2·59, whereas the Sp. Gr. of the sound diabase is 2·92.

In the decomposed portion of the intrusive dyke now under consideration, spherical nodules occur, varying in size from that of a walnut to masses with a diameter of four inches, and are encased by the ochreous matter just described. The casing easily came away, as did also a yet firmer shell, leaving in the hand a very hard core, which on fracture at once revealed the unaltered bluish diabase. The friable ochreous band in which the nodules lie is perforated in all directions, the small holes in some instances being filled with a dark powder, which on treatment with hydrochloric acid evolved chlorine, and gave other indications of manganese peroxide.

In numberless fragments of the sound diabase lying about on the floor of the quarry, there were cavities. These cavities were ¼in. deep, and of the same width in some cases, but usually smaller. Frequently they were empty, but at times contained crystals which did not

fill the cavity, and were often covered with a dark powder. By aid of a pair of tweezers and a small brush a small quantity of the powder and crystals was collected. The powder gave all the reactions of manganese peroxide, and the crystals those of calcic carbonate. In the annexed analyses the brown ochreous matter which we described as fissured in rectangular directions, and in which the nodular masses of diabase were found is marked A, and the unaltered diabase from the core of a nodule B. Samples for analyses were dried at 212° F.

	Decomposed. A.	Sound Rock. B.
SiO_2	44·93	43·56
Al_2O_3	16·27	14·58
Fe_2O_3	13·37	3·84
FeO	—	7·00
MnO	0·28	0·39
TiO_2	1·34	1·03
CaO	1·84	10·78
MgO	6·40	9·95
K_2O	0·84	1·02
Na_2O	2·08	1·86
CO_2	—	1·93
Combined Water	12·55	3·85
	99 85	99·79
Sp. Gr.........	2·592	2·923

By contrasting the two analyses one can to a certain extent follow the effect of the weathering of the diabase. The readily attacked minerals have been split up and in great measure removed, whilst there has been at the same time a concentration of the silica, oxide of iron and alumina, coupled with a large increase of combined water. The ochreous matter partakes largely of the nature of clay, and it has been clearly formed *in situ*.

To return to the "nodules." Their spherical form may, perhaps, be explained by a theory of peripheral dissolution. Let us suppose water charged with carbonic acid derived from residua of surface vegetation to have percolated to the diabase. Such a solution would attack the calcic, the magnesian, and the ferrous constituents of the rock. Assume the percolation to have also taken place between the dyke and the confining walls of granite, and to have acted upon the former laterally as well as vertically, there would in time be formed a spherical water-retaining but decomposed envelope, covering a core of still sound diabase. Some few yards east of the Fort quarry is a small quarry, also in granite similar to that of the large quarry. The granite is here also intersected by a vein of diabase, which is quite decomposed at the higher level. It was in this quarry, owing to greater facility for obtaining them, that the nodules and their outer casing of ochreous clay, analyses of which have been given, were collected. Happening to visit this quarry on one occasion as a shot was fired, it was noticed that an effect of the explosion had been to displace a block of granite three feet in a lateral direction. The block measured 40 × 21 × 24 inches. The displacement had occurred at a previously observed but barely visible crack in the granite. Adherent to the freshly exposed side of the block in several places was a pasty grey clay. Some of the clay was collected, as were also several fragments of the block of granite when broken up. Immediately over the sound granite, of which the block was a portion, lay originally some four to six feet of what was obviously the same rock in a flaky, rotten condition. As might be expected the rock near the land surface was more friable than that near the granite in course of excavation.

We give analyses of the sound granite from the block of the decomposed rock overlying it, and of the clay adherent to the block, denoting them respectively by the letters *a*, *b*, and *c*. Specimens were dried at 212° F.

	A	B	C
SiO_2 ..	70·23 ..	71·22 ..	48·44
$Al_2O_3+TiO_2$ ..	14·73 ..	14·92 ..	27·24
Fe_2O_3 ..	2·37 ..	2·36 ..	5·04
FeO ..	0·98 ..	0·07 ..	—
MnO ..	0·18 ..	0·20 ..	0·38
CaO ..	0·94 ..	0·44 ..	0·38
MgO ..	0·50 ..	0·68 ..	2·93
K_2O ..	5·13 ..	4·19 ..	7·48
Na_2O ..	4·19 ..	4·25 ..	0·35
Combined water ..	0·70 ..	2·10 ..	7·91
	99·95	100·34	100·10
Sp. Gr ..	2·65 ..	2·60	

The clay when examined with the microscope was found to contain flakes of more or less decomposed granite and particles of felspar, which explains the high figure for the potash. The clay would appear to have been formed *in situ* by the action of water percolating through the vertical fissure which we said separated the block of granite from the wall of the quarry.

We may just record the observation that the hydration of the mineral components of a rock decreases the specific gravity of the rock, as may be seen in the figures for the granite—A and B—and in those for the decomposed diabase. A few words on the mineral components of the granite and diabase may not be out of place. In the granite both the orthoclase and plagioclase felspars are well represented. The orthoclase is twinned on the Carlsbad type. Minerals accompanying the felspars are, in addition to the quartz, micro-pegmatite,

magnetite, magnesian mica, and apatite. In the diabase one recognises labradorite, augite, titaniferous iron and magnetite, also calcite and chlorite. Mr. Rutley has kindly supplied this information, not, however, as a complete account of the sections submitted to him. By way of summary we may say that one object of this paper is to show that clay is the product of the action of water holding carbonic acid in solution on rock-forming minerals, and does not result from simple admixture of finely ground sound rock with water. The following analyses are of a red sandstone and a red sandy clay from Brereton Hill, near Rugeley. When the clay was dried at 212° F., it contained 75·8 per cent. of gravelly sand. A comparison of the figures suggests a relationship between the clay and its associated rock, a question which we hope to deal with fully in a subsequent paper.

	Sandstone.	Rough Clay.
SiO_2	76·52	79·69
$Al_2O_3+Fe_2O_3$	6·76	13·26
MnO	traces	0·24
TiO_2	not estimated	0·42
CaO	6·69	nil
MgO	traces	1·03
CO_2	5·38	nil
K_2O	2·57	3·05
Na_2O	0·86	0·49
Combined water	1·20	2·02
	99·98	100·20

ON SOME FAULTS EXPOSED IN ARNO QUARRY.

By J. Lomas, A.R.C.S. (London) and Capt. A. R. Dwerryhouse.

Arno Hill, like many other eminences in the Wirral, owes its existence to a capping of hard Keuper Sandstone (f^3). Near the quarry it is 233 ft. above O.D., and slopes steeply on all sides except the north, where it makes a slight descent towards Oxton.

Entering the quarry from the South, fault rock is seen across the footpath. Following the line of fracture we come on a flank exposure on the East side of the quarry.

The fault No. 1 may be traced in a direction of about 4° E. of N. for a distance of about 120 yards. About the middle of the face a roadway crosses the line of fault, and a good section is seen on both sides.

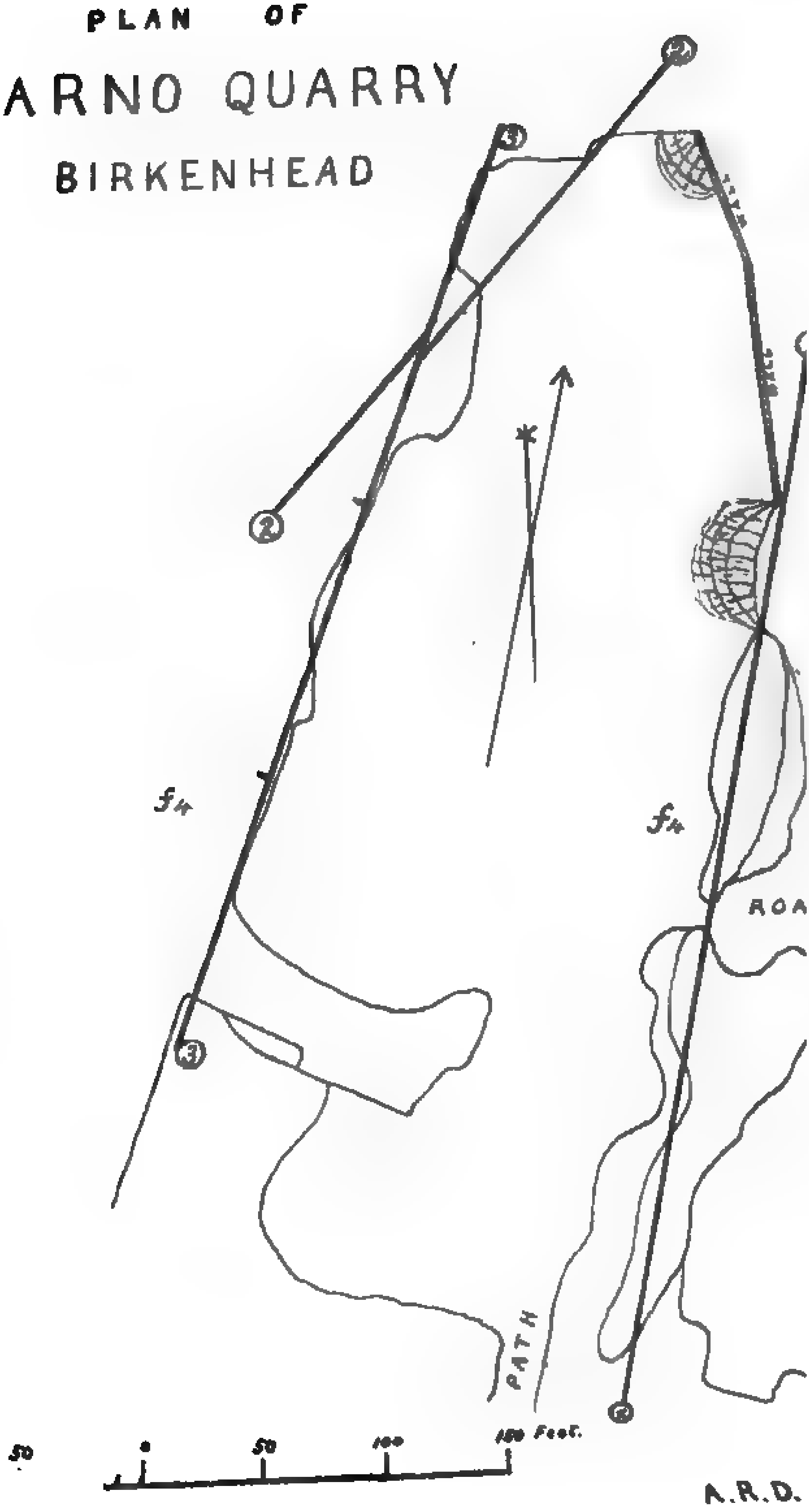
The fault rock is 5 ft. wide, the hade 30° W., and the slickensides are vertical.

The fault has brought down the basement beds of Keuper against the Upper Bunter. What the throw is cannot be determined.

Keuper Sandstone alone is exposed in the quarry W. of the line of fault, and it cannot be far from the actual base of that formation.

On the N. face we have a section—

Coarse Sandstone—5 ft.	Contains quartz, pebbles, and clay nodules.
Variegated Marl—8 ft.	
Compact Sandstone—30 ft.	Towards base of cliff it becomes coarser, and contains many clay balls and quartz pebbles.


PLAN OF
ARNO QUARRY
BIRKENHEAD
f4
f4
ROA
PATH
50
0
50
100
150 Feet.
A.R.D.

About two feet from the top of the latter bed a fine band is seen which is remarkably persistent. Dip of Keuper 6° E.

On the North face, and 13 yards from N.E. corner, another fault is seen, No. 2. It hades N.N.W. 24°. The slickensides are inclined 49° from the vertical. The throw, measured by the displacement of the marl band, is 9 ft. It can be traced obliquely across the quarry, and is seen in section on the West face.

Its general direction is S.S.W., and if continued in that direction should be visible on a cliff further along the West side; but a third fault cuts and displaces it, and we see it no more.

Fault No. 3 is seen in the N.W. corner, and again at two places on the cliff after cutting through masses of rock which project into the quarry. It can be traced in a straight line for 110 yards. It hades 13° W. and is almost parallel to the main fault.

Faults 2 and 3 cross a little distance out of the quarry, and 3 must have happened after 2, as it preserves a straight course, while 2 is displaced.

The quarry is characterised by most persistent joints, which can be traced along the floor to the cliffs on each side. The joint faces often show markings, sometimes inclined, which resemble slickensides, and it is a matter of difficulty to discriminate between faults and joints.

The quarry has not been used for a long time, and it is being rapidly filled up by rubbish. In order to preserve some record of the place we have prepared a plan and made these few notes.

The main fault is marked on the map of the Geological Survey, and is shown as continuing across Woodchurch Road and reappearing in Prenton Road, a little West of Reservoir Road.

A fault is well seen in section at this place, but we are inclined to doubt the correlation, as the fault on Arno Hill hades 30° W., and the one in Prenton Road 45° E.

In the latter section there is about 30 ft. of fault rock, and the fragments are slickensided in two main directions—45° E., which predominates, and 40° W.

On the East slope of Arno Hill, almost at the junction of Fairview Road and Bennet's Hill, and on the East side, there is another quarry, which is rapidly being filled up. It is rectangular in shape, and not more than 50 or 60 ft. long. On the South side a fault is seen with a beautifully slickensided face. It runs N.E. and S.W., is almost vertical, and has slickensides running 43° towards East. Throw about 1 ft.

Another fault is seen in the N.W. corner. It runs obliquely across the quarry in E. and W. direction, and is seen in section on the East face. It hades towards the South, and has slickensides 20° W. It has very little throw. The Quarry is excavated in the Keuper Basement Beds.

In conclusion, we would like to point out that in all these cases the general conclusions regarding the connection between direction and angle of slickensiding, given in a paper before this Society last session (Proc. 1891-2, p. 445) are confirmed.

REPORTS OF FIELD MEETINGS, 1892.

11th May, 1892.—Thingwall, Cheshire, led by Mr. J. Lomas. The Quarry described in the Paper read by Mr. Lomas at the April Meeting was examined.

4th to 6th June.—Mold District, led by Mr. T. Mellard Reade, C.E., F.G.S. The primary object of this Excursion was the examination of the drift deposits. The first day was devoted to sections within a circuit of a few miles round Caerwys village, and the extensive tufaceous deposit near the railway station was also examined. In the evening the party returned to its head-quarters at Mold. On the second day they drove to Rhydymwyn, and thence across the Halkin Mountain, to Holywell, spending some time at Moel-y-Crio, an isolated patch of sand and gravel lying on the limestone on one of the highest parts of Halkin Mountain, and afterwards returning to Mold, by way of Northop. The following day Hope and and Caergwle were visited, and the drifts of the Alyn Valley examined, as well as the river section near Cuckoo Hill, where the Bunter Sandstone was seen resting unconformably on the Millstone Grit The members returned to Liverpool in the evening.

2nd July.—Beeston. The Rocks composing the Hill were examined, and also a drift section between Beeston and Tarporley.

13th August.—West Kirby and Hoylake, led by the Hon. Secretary. Attention was given more particularly to the Rocks at Hilbre Point and Redstones, with regard to their relation to the Rocks of Hilbre Island.

10th Sept.—Hilbre Island. The Conglomerate bed of Middle Island was carefully examined and traced to Hilbre, but the lower Conglomerate at the northern end of Hilbre Island was not seen.

1st October.—Hale, led by Mr. J. Lomas. In spite of the unfavourable weather a very careful examination was made, under the direction of Mr. Lomas, of the deposits and Glacial markings between Hale Head and Decoy Marsh, afterwards described in the Paper read 13th December.

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* Have read Papers before the Society.
† Contribute Annually to the Printing Fund.

PROCEEDINGS

OF THE

Liverpool Geological Society.

SESSION THE THIRTY-FIFTH,

1893-94.

Edited by H. C. BEASLEY.

(The Authors, having revised their own Papers, are alone responsible for the facts and opinions expressed in them.)

PART 2. VOL. VII.

LIVERPOOL:
C. TINLING AND CO., PRINTERS, VICTORIA STREET.
1894.

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LIST OF SOCIETIES, ETC., TO WHICH THE PROCEEDINGS OF THE LIVERPOOL GEOLOGICAL SOCIETY ARE SENT.

(Publications have been received in exchange during the Session from those marked).*

*Academy of Natural Sciences, Philadelphia.
Advocates' Library, Edinburgh.
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*Birkenhead Free Public Library.
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*Geological Survey of Arkansas.
*Geologists' Association, London.
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*Imperial Academy of Naturalists, Halle, Prussia.
Kansas Academy of Sciences, Topeka, U.S.A.

*Leeds Philosophical and Literary Society.
*Leeds Geological Association.
Liverpool Athenæum.
,, Chemists' Association.
* ,, Free Public Library.
* ,, Geological Association.
,, Literary and Philosophical Society.
,, Lyceum Library.
,, Philomathic Society.
,, Engineering Society.
,, Astronomical Society.
,, Science Students' Association.
L'Universite Royal de Norvége, Christiana.
Manchester Association of Engineers.
*Manchester Literary and Philosophical Soeiety.
*Manchester Geographical Society.
*Minnesota Academy of Natural Science, Minneapolis, U.S.A.
Musée Royal d'Histoire Naturelle de Belgique.
Museu Nacional, Rio de Janeiro.
Museum of Practical Geology, Jermyn Street, London.
*North of England Institute of Mining and Mechanical Engineers.
*New York Academy of Sciences.
*Owens College, Manchester.
Patent Office Library, 25, Southampton Buildings, Chancery Lane, London, W.C.
Rassegna delle Scienze Geologiche in Italia.
*Rochester N.Y. Academy of Science.
*Royal Dublin Society.
Royal Geological Society of Ireland, Dublin.
Royal Society, London.
*Smithsonian Institution, Washington, U.S.
*Société Geologique de Belgique, Liége.
Société Geologique du Nord, Lille.
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,, ,, Liverpool.
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Watford Natural History Society.
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*Wisconsin Academy of Sciences, Arts, and Letters, Madison, U.S.A.
*Woodwardian Museum, Cambridge.
Yorkshire Geological and Polytechnic Society.

PROCEEDINGS

OF THE

LIVERPOOL GEOLOGICAL SOCIETY.

SESSION THIRTY-FIFTH.

OCTOBER 10TH, 1893.

E. DICKSON, ESQ., F.G.S., in the Chair.

The following gentlemen were elected Officers and Members of the Council:—

Vice-President—H. ASHTON HILL, M.INST. C.E.

Hon. Treasurer—THOS. GOFFEY.

Hon. Librarian—J. J. FITZPATRICK.

Hon. Secretary—H. C. BEASLEY.

Members of Council—A. R. DWERRYHOUSE, C. RICKETTS, M.D., F.G.S., J. LOMAS, T. MELLARD READE, C.E., F.G.S., and J. TWEMLOW.

The President then read the Annual Address:—

THE ESTUARY OF THE RIBBLE.

NOVEMBER 14TH, 1893.

The PRESIDENT, E. DICKSON, Esq., F.G.S., in the Chair.

FRANCIS EDWARD CANE, M.D., S.S. "Scythia," proposed by J. J. FITZPATRICK and Dr. RICKETTS, was elected an Ordinary Member.

ALEYN LYELL READE, Park Corner, Blundellsands, proposed by T. MELLARD READE and H. C. BEASLEY, was elected an Associate.

EXHIBITS:—

Photographs and Specimens, illustrating the Geology of the Neighbourhood of Nottingham; and Flint Implements, forged and genuine. Dr. C. Ricketts.

Footprint from Trias of Massachusetts. The Hon. Secretary, for Mr. Norman Thomas.

New Geological Map of the Neighbourhood of London. The Hon. Secretary, for Messrs. Philip, Son and Nephew.

Neolithic Flint Implements, from Randers Amt, Jutland. F. C. Caröe (Visitor).

Flint Implements from Larne. H. C. Beasley.

Mr. W. E. Cox (Visitor) exhibited Specimens and described a recent find of worked Flints of an early period, near Spital.

The following Paper was read and illustrated by experiments:—

THE ARTIFICIAL PRODUCTION OF PERLITIC STRUCTURE.

By JOSEPH LOMAS, A.R.C.S.

DECEMBER 12TH, 1893.

The VICE-PRESIDENT, H. ASHTON HILL, Esq., M.I.C.E., in the Chair.

EXHIBITS:—

Carboniferous Fossils, &c. H. Ashton Hill.

A Glaciated Flint and Slabs of Sandstone, from Storeton and Flaybrick. Dr. Ricketts.

Dr. Ricketts described a large fragment of bone of a Whale, found in digging the foundations of the New Post-Office.

The following Papers were read :—

THE OCCURRENCE OF PHOSPHATE OF IRON COATING SAND GRAINS AT TRANMERE.

By W. Mawby.

NOTE ON A SECTION OF THE TRIAS ON THE SEACOMBE EXTENSION OF THE WIRRAL RAILWAY.

By H. C. Beasley.

JANUARY 9th, 1894.

The President, E. Dickson, Esq., F.G.S., in the Chair.

T. W. Davies, M.I.C.E., 3, Burns Avenue, Sea View Road, Liscard: proposed by T. M. Reade, C.E., F.G.S., and H. C. Beasley; and

R. Valentine Harvey, Merelands, Blundellsands: proposed by H. C. Beasley and W. Hewitt, were elected Ordinary Members.

EXHIBITS :—

Geological Photographs. O. W. Jeffs.

Illustrations of Slaty Cleavage. T. M. Reade.

Graphic Granite. J. Lomas.

Minerals and Meteorites. J. J. Fitzpatrick.

Flints, &c., from the Boulder Clay. Dr. Ricketts.

Permian Fossils from Skillaw Clough. The President.

Auriferous Conglomerate from Witzwater-randt. The President.

Cornish Minerals and cleaved Slate shewing Series of Miniature Faults. H. C. Beasley.

Photographs of Canary Islands. J. H. T. Ellerbeck.
Microscopes. J. Lomas, A. R. Dwerryhouse, and H. C. Beasley.

Each exhibitor described at length his exhibit, and no Paper was read.

FEBRUARY 13th, 1894.

The PRESIDENT, E. DICKSON, Esq., F.G.S., in the Chair.

HENRY WOODWARD, Esq., LL.D., F.R.S., President Geol. Soc., F.Z.S., &c., &c.: proposed by T. Mellard Reade, F.G.S., and Dr. Ricketts, F.G.S., was elected an Honorary Member.

EXHIBITS :—

Specimens of Artificial Sandstone. A. R. Dwerryhouse.
Jaw of Red Deer from Southport; some Shell Breccia from the Irish Sea. E. Dickson.

The following Papers were read :—

ON SOME SHELL BRECCIA DREDGED IN THE IRISH SEA.

By THE PRESIDENT.

THE SEA BOTTOM OF LIVERPOOL BAY, &c.

By Prof. W. A. HERDMAN.

MARCH 13TH, 1894.

The PRESIDENT, E. DICKSON, Esq., F.G.S., in the Chair.

The following Papers were read :—

THE DUBLIN AND WICKLOW SHELLY DRIFT.

By T. MELLARD READE, F.G.S.

NOTES ON THE TRIAS OF NEW JERSEY, U.S.A.

By W. MAWBY.

APRIL 10TH, 1894.

The PRESIDENT, E. DICKSON, Esq., F.G.S., in the Chair.

HAROLD E. GARDNER, B.A., Windyknowe, Blundellsands: proposed by Thos. Goffey and T. Mellard Reade; and THOS. MOLYNEUX, C.E., Earlestown: proposed by Thos. Goffey and T. Mellard Reade, were elected Ordinary Members.

EXHIBITS :—

Paradoxides Limestone from the Cambrian at Comley, Salop. By the President.

Specimens from Broken Hill, Australia, and Fossils in Slate. T. Mellard Reade.

Fossils from Wenlock and from the Onny Section. Dr. Ricketts.

The following Paper was read :—

THE PERMIAN CONGLOMERATE OF THE VALE OF EDEN.

By J. J. FITZPATRICK.

FIELD MEETINGS were held :—

1893.

May 19-23.—At Belfast, led by T. Mellard Reade, C.E., F.G.S.

July 1.—At Arno Hill, Birkenhead, led by J. Lomas.

Aug. 19.—At Doulton's Delph, St. Helens, led by J. Lomas.

,, 26.—At New Well of the Wallasey Waterworks, led by H. Ashton Hill.

Sept. 9.—At Helsby, led by H. C. Beasley.

1894.

Mar. 23/27.—At Church Stretton, Salop, led by Dr. Callaway, F.G.S.

LIVERPOOL GEOLOGICAL SOCIETY,

Dr. *In account with* Edwd. M. Hance, *Hon. Treasurer, Session* 1893-94. **Cr.**

Dr.	£	s.	d.	Cr.	£	s.	d.
To Hon. Secretary's Expenses, 1891-2	2	17	1	By Balance brought forward	4	18	7
,, Rent, 1891-2	5	0	0	,, Subscriptions for Session	19	18	6
,, Doling, for current Session	7	16	0	,, ,, Arrears	8	18	6
,, Hon. Treasurer's Expenses for current Session		1	7	,, ,, in Advance	1	11	6
,, Amount paid Tinling & Co. (Printers), on a/c	20	0	0	,, Special Donations		19	0
,, Balance		18	1	,, Sale of Proceedings		6	8
	£36	12	9		£36	12	9
				By Balance carried forward	£0	18	1

Audited and found correct,

7th October, 1894.

(Signed), H. ASHTON HILL.
W. HEWITT.

PRESIDENT'S ADDRESS.

THE RIBBLE ESTUARY, WITH NOTES ON THE FORMATION OF SAND AND THE DISPOSAL OF DISSOLVED MATTER IN RIVER WATER.

By E. Dickson, F.G.S.

In accordance with the custom of our Society, which requires from its President at the opening of each session some remarks in the nature of an Introductory Address, I propose this evening to direct your attention to the subject of the Ribble Estuary, and, as more or less bearing upon it, to the question of the formation of sand in our estuaries, making in conclusion a few observations as to the disposal of the dissolved matter in river water. In 1887 I read a paper before this Society on the excavations for the Preston Docks, and in it gave a description of the works proposed to be done and the deposits met with in the construction of the docks, and in the making of a new river channel below the Castle Hill at Penwortham. In this same paper a list is given of the bones, human skulls, and other remains found during the course of the excavations, and attention is called to the exceedingly large number of Urus heads found in the comparatively restricted area in which these excavations were made. In the following Session I read a further paper on the same subject, which contained, in addition to an extended list of the bones and remains found up to the date of that paper, a description of a boat found in 1887 during the

excavations. A section is also given of the bed of the Ribble from the docks to a distance of seven miles towards the bar. Since 1888 many additional objects have been obtained from the excavations, and the following complete list of what has been found up to the present time has been kindly supplied to me by my friend Mr. Shortt, the Hon. Curator of the Museum at Preston, where the various objects found during the course of the excavations are to be seen.

40 heads of Urus.
18 fragments of ditto.
54 antlers of stags.
45 fragments of ditto.
3 skulls of thick palated Pilot Whale.
2 fragments of vertebrae of ditto.
1 part of jawbone of Right Whale.
1 skull of grampus.
1 ditto of the porpoise.
21 human skulls.

The collection of Urus heads, as obtained from one locality, is probably unique, although the number given above probably only represents one half of what were actually found. They are of all sizes, and have evidently belonged to animals of all ages. When the railway bridge, by which the L. & N.W. Railway crosses the Ribble near Preston, was being built, antlers of red deer and Urus heads were met with. Both antlers and heads have been met with again at Ashton, about one and a-half miles below Preston, and taking into account the area over which this immense accumulation of animal remains has been found, one is startled at the abundance of the creatures in the Ribble valley at apparently one and the same time; the depth of the deposit being approximately the same, 12 to 14 feet.

The horns and heads are, for the most part, uninjured, and it is therefore fair to assume that they cannot have travelled far. It seems not altogether improbable (as Mr. Shortt has suggested) that the whole of these animals were entombed at one and the same time, in consequence of some prodigious storm. The configuration of the Ribble valley is such, that in places it would only require a comparatively slight obstruction to keep back for a time the river waters so as to form an enormous reservoir, to be poured forth as a devastating flood on the removal of the obstruction.

As will be seen on reference to the Section which I have before referred to, the deposits consist of grey sand resting for the most part on gravel, except at a point three miles from the docks, where the grey sand rests on a blue clay containing layers of peat which, from the description given to me by the dredging master, I believe to belong to the Formby and Leasowe Marine Beds of Mr. Reade. This gravel for the first four miles rests either directly on the red sandstone of the pebble beds or else on Boulder Clay; but after the fourth mile, and from that to the seventh, the sand and gravel rest on red marl, which is undoubtedly Keuper marl.

It has been the ambition of various successive companies and individuals almost from the beginning of this century to convert Preston into a sea-port, and to make the river available for ships of large tonnage, but the physical difficulties with which all such promoters have had to contend are well nigh insuperable, owing to certain peculiar characteristics of the Estuary; and it is to the nature of these characteristics that I wish to draw your attention this evening.

The Ribble rises, as is well known, at Ribble Head, near Ingleboro', in Yorkshire, and then flows in a South-

westerly direction past Settle, Clitheroe, Ribchester, and finally to Preston; the first portion of its course being over, or through, rocks of Carboniferous age, then over Triassic rocks, and, near Preston, through a country thickly covered with drift. When the river once has entered the drift country, it rarely succeeds in cutting down the surface of its bed to the rock itself; and as the river has, at this stage of its course, extended to the lowest gradient of fall, its denuding power must consequently be confined to lateral denudation of the banks. Where the rock is protected by Boulder Clay, the river has failed to cut through the clay to the rock beneath; but where, as in the case of the excavation for the new river diversion, the clay has been removed, the rock beneath is seen to be channelled and grooved by undoubted river action. Another proof of what I think is preglacial denudation, is found in the exceedingly rugged appearance presented frequently by the underlying rock on the removal of the overlying gravels and clay. The section of the river bed between Penwortham Bridge and the Chain Caul shows how rugged and uneven is the surface of the underlying rock forming the bed between these points, and borings taken in other parts of the river show that this uneven surface is by no means local.

Owing to the cause to which I have above alluded, namely, the fact that the river in the lower portion of its course has reached the lowest possible gradient of fall, we find evidences of old channels and old river courses over the whole of the wide valley through which it flows, that is to say, from Samlesbury Bridge to below Preston. A leading characteristic of the Ribble, and one which has caused the greatest difficulty to those interested in improving it for navigable purposes, is the fact that its

channels are so unstable. An old map of Preston dated about 1728, and also a later map of 1809, show that the river channel at those dates was exactly where the new channel has now been cut for the river below Penwortham Hill in connection with the New Dock works, although, to cut this new artificial channel a thickness of 20 to 30 feet of sand and gravel has had to be excavated.

The drainage area of the Ribble is stated by Mr. de Rance, in "The Superficial Geology of the Coasts of South-West Lancashire," at 585 square miles, though Sir John Coode, in his evidence before a Parliamentary Committee, states it to be 880 square miles. The upland water discharged by the Ribble is very variable. The volume of water which comes down during periods of flood is undoubtedly very great, but I feel inclined to question Sir John Coode's estimate, viz.: that the average quantity of upland water discharged by the Ribble is about 140,000 cubic feet per minute, for this would mean a daily flow of 1,360,000,000 gallons. Now, the average diurnal discharge of the Thames at Teddington has been calculated at not more than 380,000,000 gallons, and inasmuch as the drainage area of the Thames is 3,670 square miles, it seems probable that the estimate of 140,000 cubic feet per minute for the Ribble, with a less drainage area, must be an excessive one. Calculations of river volume and discharge ought to be made with the greatest care, as very erroneous deductions may be only too readily drawn from experiments and calculations not conducted with due regard to all the circumstances which estimates of this nature require. Whatever may be the correct estimate for the water discharged daily by the Ribble, this river unquestionably brings down an enormous amount of detritus as the waste from the drift, the area of which

Mr. de Rance estimates at 380 square miles. As evidence of river contribution, I may mention that during the first three or four years after opening the artificial river channel below Penwortham Hill, detritus accumulated in it to the extent of over 200,000 cubic yards. Apart from detritus, rivers carry a great deal of matter in solution, so that taking Sir J. Coode's estimate of the average amount of upland waters passing down the Ribble, which, as I have said, he puts at 140,000 cubic feet per minute, and taking the soluble solids in the water at 14·28 grains per gallon (a mean from the analysis of the water of 30 rivers, equivalent to 89·02 grains per cubic foot), the Ribble would contribute to the sea about 400,000 tons annually. The soluble solids consist of carbonates of lime and magnesia, sulphate of lime, silica, oxide of iron, oxide of manganese, and salts of the alkalies potash and soda, all constituents of rock-forming minerals. If we take the calcareous matter only, viz., 62·4 grains per cubic foot, and assume the same flow, this matter alone will amount to not less than 300,000 tons annually.

The distance from Preston to the Bar is about 16 miles, and the fall very slight, not exceeding 6 inches per mile.

Before 1806 the whole space between Preston and the sea might be considered as estuary; but, owing to operations to which I shall presently refer, for the first three miles below Preston the Channel must now be regarded as a river rather than as an estuary. As far as I can ascertain, before 1806 nothing was done either as regards reclaiming riparian marsh land or in attempting to regulate the Channel by training walls; but later on works appear to have been carried out at different times having both the above objects in view.

In 1853 an act was obtained by a Company to improve the navigation of the Ribble, and to this end training walls were put down in different parts of the estuary, the intention being that the tidal water should, instead of being allowed to wander over the estuary, be directed into one channel. It was supposed that the scour of the ebb tide would always be sufficient to preserve the channel.

No further action was taken with the view of improving the navigation of the Ribble until the year 1883, when the Preston Corporation obtained Parliamentary powers to take over the Company and to make certain works with the same object, namely, of improving the navigable facilities of the river.

The Corporation also adopted the plan of confining the river within training walls, but in their scheme powers were also obtained to dredge the bed of the river as well, so as to make the fall three instead of six inches to the mile between the entrance to the Dock and the Bar. Now it is curious to note the effect these training walls have had upon the Ribble Estuary, and in this connection to read the remarks of Mr. Binney, in a paper read before the Literary Society of Manchester in 1873. Mr. Binney, alluding to the Mersey, states that "the contraction by embankments of the Mersey by diminishing the quantity of water entering at the flow has diminished the scour of the ebb," and exactly what Mr. Binney stated with regard to the Mersey has indeed taken place in the case of the Ribble. Between 1854 and 1888, nearly 5,000 acres of estuary were reclaimed, the effect of which has been to reduce the tidal volume to a very considerable extent, as each cubic yard of reclaimed land means one cubic yard less of tidal water and a proportionately less amount of scour. From

evidence given by Sir John Coode before the Parliamentary Committee in 1883, it was calculated that at the time the evidence was presented, the quantity of tidal water of the ordinary spring tide flowing to Preston above Lytham was 430,000,000 cubic feet per tide, and it was estimated that if the proposed dredging were carried out, the quantity of tidal water would be increased to 700,000,000 cubic feet.

It is interesting to observe the method by which the solid accretions due to these walls is effected.

Walking over a portion of the marsh bordering the Estuary, one meets first with fine mud, then coarser mud mixed with sand, then fine sand, and finally in the channel itself coarse sand, all deposited as it were in the order of their gravities. The finer grains are deposited on the outside of the training walls owing to a decrease of velocity, and further inland the finest mud is deposited where the water is shallower, and the force of the current at a minimum. The deposition of this finest mud is largely assisted by the grass and samphire which obstruct the current and also act as filters. When by the accretions the level of the marsh has been raised to a point beyond the reach of the ordinary tides, the samphire begins to grow and is after a time followed by grass, so that the marsh from being a plain of unproductive sand becomes in time alluvial marsh of exceeding value from an agricultural point of view. In fact the effect of the training walls in the Estuary, while increasing the flood in the trained channel, has been to increase the stagnation in the rest of the Estuary. Thus, during the last fifty years owing to the policy which has been followed, the whole of the inner portion of the Estuary between the Naze Point near Lytham and the Chain Caul about one and a quarter

miles below the Preston Dock has been converted into fields and productive marshes, where formerly was sand intersected by shallow winding channels. Again, before 1853 hard red sand passable by carts at low tide composed the whole of Hesketh Marsh between Hesketh Arms and the Guide's House, which is now good land for agricultural purposes.

This silting up behind training walls has been observed in the case of several other rivers, where conditions similar to those of the Ribble prevail. For example, a deposit of three feet was formed by the Humber in two and a half years. Near the mouth of the Avon, and also in the case of the Severn, the placing in of walls caused a silting of the shore to the extent of thirty-two feet in seven years. In the Seine too, works carried on between 1843 and 1869 have caused a silting over of about 25,000 acres. Mr. Vernon Harcourt in 1875 estimated that 274,000,000 cubic yards of tidal capacity had been abstracted from the estuary of the Seine since the works were commenced, and calculated the deposit from 1835 to 1880 to exceed 40,000,000 cubic yards. The same authority also points out that the height of training walls in estuaries does not alone determine the height to which the accretion may rise behind them, as considerable tracts in estuaries are frequently raised by warping up to high tide level, and that in fact it is the constant change of channel occurring in a natural sandy estuary which prevents the silting up of the estuary. It is therefore quite possible to imagine that a similar result might be brought about by natural means such as warping, as we find artificially produced by aid of training walls, although training walls have the advantage in that we can examine the effects more thoroughly, owing in a great measure to the

comparative rapidity of the growth of the accretion caused by them.

There would appear to be no reason to doubt that the decrease of tidal capacity in any estuary by the reduction of the volume of the tidal ebb and flow is to cause almost immediate accretion. I have tried to obtain particulars of the amount of sand and alluvial matter held by the tide in the Ribble Estuary at ebb and flow respectively. The only data, so far as I know, are some given by Mr. G. N. Abernethy, who says he found the flood water at the bar comparatively clear, but that after it had passed a short distance up the channel to No. 8 Buoy opposite St. Anne's, it became thickly charged with sand and light alluvial matter to the extent of about 62 grains to the cubic foot, and to the extent of 97 grains to the cubic foot at Lytham Pier. These results, I believe, were the means of several experiments; but as no full data are furnished, I do not feel entitled to draw deductions from them, though at the same time will not pass them over, as they are the only figures on the subject that I know of.

But in the case of the Ribble Estuary, there are other causes which, in addition to the tendency to accretion, interfere with attempts to improve its navigable qualities. The bed of the Estuary covers an area of 57 square miles, and is composed of fine sand overlying gravel, which rests on Boulder Clay. This bed is readily affected by the strong flow and ebb currents due to the large tidal range, amounting to 27 feet 3 inches ordinary spring tides, and to 13 feet ordinary neap tides. The charts of the channel to which I will presently refer, show that the main outfall channels are in the northern and southern parts of the Estuary; that the Northern Channel is extremely

prone to change of position, and that the Southern Channel from the sea to Southport, and for half a mile north of Southport Pier is not so liable to this change as are the other channels, and that it has in fact practically maintained its position since 1736.

The charts also bear witness that before any reclamations were made, or the Estuary interfered with, there were always two channels navigable for vessels of small tonnage, and that whenever the main channel became split up into two or more channels the navigable channel immediately deteriorated.

In many respects the Estuary of the Ribble resembles the Estuary of the Tees, and also those of the Tyne, of the Clyde, and of other British rivers, but with this difference, that none of them have sand banks seaward of their embouchures. In the Ribble Estuary there is a range of sand banks six miles wide and seven long, which extends seaward beyond Lytham, and is exposed to the full force of the sea during westerly gales.

Owing to the action of the sea in periods of storm the banks constantly vary in form, and change their position according to the set of the currents. The frequent alterations of position of the channels passing through the Estuary, and in the Estuary itself, are very clearly shown on an examination of the various available charts of the Ribble Estuary. Were there a sufficient number of early charts in existence, I feel assured that they would show that constant and marked changes go on in the height, shape, and position of the banks, and the depth, breadth, and direction of the channels. I have examined a large number of charts of the Estuary, and will give you shortly a description of the channels on some of the principal ones, which will, I think,

make clear to you how important have been the changes in position both of the channels and of the banks.

The earliest chart of the Ribble Estuary in the British Museum is one made in 1689, on which are shewn two channels open to the north, divided by only a slight belt of sand, and a short south channel open from Lytham to Southport.

A chart of 1736, by Fearon & Eyes, shows that instead of two channels to the north, there was one narrow channel up what is now called the "North Hollow," and that the main channel was at that date up the centre of the Estuary. There is also shewn a South Channel from Formby Point past what is now Southport, and a communication between Crossens Pool and the main channel.

A chart of 1761, by Mackenzie, shows also three channels in the Estuary, but their direction and the position of the sand banks have altered since 1736. There is also another chart by Mackenzie, in 1786.

Billing's map of 1786 shows the river above Lytham, opposite the Guide's House, fordable at low water, and a good South Channel running by Southport.

A chart of 1796 shows the North Channel and the South Channel, but only a very short central Channel.

Another chart, dated about 1809, shows a main channel in the Estuary passing by the Lytham shore, and a buoyed channel down the centre. The North Channel appears blocked up at the South East end. The South Channel is buoyed and appears blocked at what is now Crossens. The position of the banks is also very different to that shown on the earlier charts.

Brazier's chart, of 1820, shows a main channel through what is now the Pinfold or Gut Channel, but not a trace of the North Channel. The South Channel, which in the chart of 1809 is shown as blocked up at Crossens, from this chart appears to run through to the main channel, and there is a communication between the Crossens Pool and the South Channel. Opposite Southport at this date a depth is shown of 24 feet at low water. A comparison of this chart with that of 1809 abundantly proves how extensive have been the changes in position of the banks in so comparatively short a period as eleven years.

The next chart is one by Captain Brazier, in 1837, which gives a fairly good channel to the South, and one to the North, the South Channel running up in a north-easterly direction, nearly opposite to Lytham.

A chart by Stevenson, of 1852, gives a broad South Channel connected with Crossens Pool but totally unconnected with the main channel, the intervening space being occupied by sand banks. There is, however, shown a good North Channel, and a central Channel which is called the New Gut. For navigable purposes the river in 1852 seems to have been better than in earlier, or indeed, in later times.

The last chart I will mention is one by Calver, dated 1860, which shows two channels, the North Channel and Central Channel. The channel running out of Crossens Pool ran (in 1860) into what is now the Bog Hole opposite Southport, which then had a depth of about 30 feet at low water. There is a narrow communication shown between the Pinfold and South Channel, but none between the South Channel and Central Channel.

If the channels as given in Belchers' chart of 1837 are compared with the channels as shown on the Admiralty charts of 1889, it will be seen at a glance how considerable have been the changes in the Estuary during fifty years. In the case of an estuary like that of the Ribble, it would seem that it is the scour of the tidal water, and not the upland waters brought down by the river, that keeps the main channel open. The duration of the flood tide in the Estuary during spring tides is four hours and that of the ebb tide eight hours. The flood tide must therefore run at a greater speed than the ebb, since the time is less, the difference in the velocity being from half to three-quarters of a mile per hour. The greatest velocity of the flood was estimated by Mr. G. N. Abernethy at 3¾ miles per hour, and that of the ebb at 3¼.

The flood comes in with a bore, passing rapidly over the sands and carrying with it detritus, which the ebb by reason of its lower velocity has not the power to remove. In addition to the sand and sediment brought up by the flood an immense quantity of sand is also washed into the channels by the water flowing from the surrounding banks. As a result of this contribution a vast accumulation of sand takes place, which the ebb tide cannot remove. In this way the banks and channels in the Estuary alter in form and position more or less at every tide, and it is no uncommon occurrence after a storm for a channel to be entirely obliterated.

In consequence of the fall in the river bed being decreased by the dredging operations, a larger quantity of sand has been brought in at each incoming tide than was formerly the case; and it has been stated that in the channel from the west end of the new diversion to a point seven miles down the channel, there had been

between 1883 and August 1889, a deposition of 636,000 cubic yards of sand.

An effect of the training walls in the Estuary has been not only to make the gut or centre channel straighter, wider, and deeper, but to so increase the scour of the tide that between 1882 and 1889 it has been enabled to cut its way through a bank of sand 12 feet above low water level. As will be seen by the section referred to in my paper read in the 1888 Session, this central channel is blocked by the large dams of marl, which, occupying the bed of the river between Lytham and the Naze Point, have had the effect of keeping back the water and diminishing its velocity. It is anticipated, however, that when by further dredging these obstructions to the tidal flow shall have been removed, the scour will be increased and the sand got rid of.

As regards the blockage of river channels in estuaries, a further cause retarding the tidal flow and tending to pile up banks of sand is the circuitous route of a channel and the inequality of its bed. These remarks especially apply to an estuary like that of the Ribble. In the opinion of the dredging master the form of the sand banks in the Estuary is determined more by the strength of the flood tide than by that of the ebb tide; but on this point further information is, I think, desirable. It has always been a matter for surprise, since sandbanks are so prone to alter their position, why the remarkable depression opposite the end of the pier at Southport, and known as the Bog Hole (in consequence of peat occurring below the sand), should have so long maintained its present position and depth.

On comparing the various charts, it would seem that the depth of the Bog Hole is greater now when it is a blind channel, than it was when connected with the

main channel flowing past Lytham. The reason for this increased and continued depth is doubtless that the eddying motion set up by the flood tide has an excavating action, an action which would not occur were the Southern Channel again connected with the Northern, which has been frequently the case during the last 100 years. In my opinion, if the North and South Channels should again become connected, the probable result would be that this deep water depression opposite Southport would be shallowed, or possibly silted up altogether.

The Bar which lies more or less opposite the central channel, and which may be regarded rather as an isolated sandbank than as a continuous ridge of sand thrown across the channel, has varied in form very little during the last thirty years, and rests on a bed of hard Boulder Clay.

Bars which block the entrance to most rivers—for example, to the Nile, the Mississippi, the Tay, &c.—have not always the same origin. The two agents chiefly concerned in their formation—the waves and the tidal scour—are in constant opposition to one another, so that a general principle which should guide engineers would be to preserve a sufficient quantity of tidal water to counteract the tendency of the sea to heap up detritus at the mouths of rivers.

I think it might be interesting were I to give you an idea what some of these so-called channels in the Ribble Estuary are like. I will therefore read to you a description by one of the engineers of the North Channel.

"For the first two miles at the Lytham end no low water channel at all, and the sandbanks stand 10 feet above low water; then for a mile there is a low water channel 4 feet to 14 feet in depth, then 10 chains of dry

sand, the sand being three feet above low water; then 70 chains of low water channel 3 to 13 feet in depth; the remaining length of 1 mile, 25 chains, being dry, and varying from three to four feet above low water." In the North Channel, therefore, there would appear to be, or rather there was in 1888, 1 mile, 70 chains, low water channel, and 5 miles, 30 chains, of accumulating sandbanks. Borings have been made along the bed of this North Channel, through the sand and gravel, down to the Boulder Clay beneath, and all across the Estuary from the end of the South Channel to a point near Lytham; and a noteworthy feature which these borings have revealed, is the extremely irregular surface of the clay beneath the sand and gravel.

At various times Liassic fossils have been found on the shores of the Estuary at Hesketh Bank, at Lytham, and on the coast near Blackpool, and it has been suggested that possibly in the Ribble Estuary there was a small patch of Lias. I have been hoping that, from information afforded by the various borings or dredgings, the question as to the existence or non-existence of Lias in the Estuary could be settled; but I am satisfied that, so far, no trace of Lias has been met with.

A chief obstruction to the dredging has been the occurrence of an immense quantity of boulders, varying in weight from three tons downwards.

There is another matter which bears more or less directly on the subject we are now considering, and one to which I think sufficient attention has not been drawn, and that is the question of the manner in which the sand as found in our estuaries has been formed.

When rocks in the presence of water decompose chemically, the more soluble constituents disappear first, leaving the quartz grains and other forms of silica as a

residue. Sand, using the term in its geological sense, is not merely SiO_2 (quartz), though undoubtedly very largely composed of this body. Sand is made up of highly complex alumino-ferric and magnesian silicates, which are of almost infinite variety and composition. Many of them, as rock-forming minerals, will long persist under conditions that sufficed to split up the parent mass whence they were derived; some in fact, though in fine powder, powerfully resist even strong acids. The chemical composition of such silicates will then to a great extent determine the so-called "life" of the minerals in the sand. Rivers naturally carry down in solution the constituents dissolved from rocks in their drainage area. The bases potash and soda formed in all natural waters, are proximately derived more or less from the felspars of the igneous rocks, so that the rocks that yielded these bases must have been chemically and not merely mechanically decomposed. Silica, which was previously combined with the potash and soda of the felspars, has been set free. This silica is, however, not sand, but judging from chemical analogy is, when set free, in solution in water, and may very likely at some later period play an important part in the genesis of other rocks and sinters.

Dealing still with a rock—some of its components are more readily attacked than others; and it is clear that the removal of the more soluble ones will open up the rock to a general disintegration by chemical as well as by physical forces—such, for instance, as flowing water or tidal action. The rock when disintegrated offers of course a large surface of action to water, an action which must in time be paramount, whereby everything that water can dissolve from the rock particles will be removed, leaving only the highly insoluble quartz grains.

Inasmuch then, as water, by removing the bases viz., the iron, alumina, magnesia, lime, &c. that compose rock-forming minerals, so breaks them up, it is reasonable to infer that for rocks in which a large variety of minerals occur, the minerals will disappear in the order of the resistance to the agencies just mentioned. Thus by way of summary I may say that sand is mainly quartz, plus the débris of the more resistful of the minerals that formed the rock or rocks which gave it birth.

Thus far I have considered the Ribble in regard to its channels, their change of direction in recent times, the effect of training walls, the deposit that collects at the river's mouth, and the nature of the deposit, and by an appeal to chemical facts, why the sand which so often blocks the channels consists mainly of quartz. What is true in many respects of a comparatively small river like the Ribble will be true of rivers in general. I will now briefly in conclusion consider the disposal of the dissolved matter in river water, or at any rate the disposal of some of it, ere the river reaches the sea. The calcareous salts, the silica, the iron, the manganese, and probably some alumina, go to build up the multiform inorganic structures of aquatic animals and plants. The shells of fresh water molluscs and the bony skeletons of fishes consist of these bases, which the organisms by their vital functions must have eliminated from the medium in which they dwell. Taking aquatic plants, I may mention the Characeæ and the various fresh water Algæ. The ash of Chara fœtida, Schultz Fleith found to contain in 100 parts 55·73 of lime, 0·57 of magnesia, and 42·60 of carbonic acid, showing the ash to be chiefly carbonate of lime. It is further stated that the ash amounted to 66·7 per cent. of the dried plant. It is probable that silica and iron were also found in the ash, since the ash of plants is

and the coarseness of the structure he found to depend (1) on the thickness of the layer of balsam, and (2) on the coarseness of the emery used in roughing the surface of the glass.

Perlitic structure must be regarded as resulting from the shrinkage of a brittle substance when parts are so held that the whole mass cannot contract as one piece.

Pour warm Canada balsam over a sheet of smooth glass. On cooling, the layer, if brittle, will break away from the glass and remain one piece, except perhaps for a few, long straight cracks, which may break it up into polygons (Fig. 6). But pour the same over a piece of roughened glass and the grip of the balsam on the irregular surface is too great to allow the layer to come away *en masse*.

In that case shrinkage will divide up the cooling matter into areas of contraction, each one of which will act as an independent centre of contraction.

The first cracks to appear are long and fairly straight; they run either parallel or are inclined at low angles to each other. The irregular areas thus produced are usually very long as compared with their width. They, however, soon get broken into smaller parts by transverse fractures. Next, the angles of these polygons are cut across, and then appear the beautiful curved cracks, which are so characteristic of perlitic structure (Figs. 1 and 2).

The curved cracks are rudely concentric, but it is not often that complete rings are seen. Sometimes they are spiral, the inner curves being at a lower level than the outer. They resemble a wire wound round a cone from base to apex, the apex being fixed to the glass. The spiral is extremely well developed in some specimens I have prepared from Copal (Fig. 5).

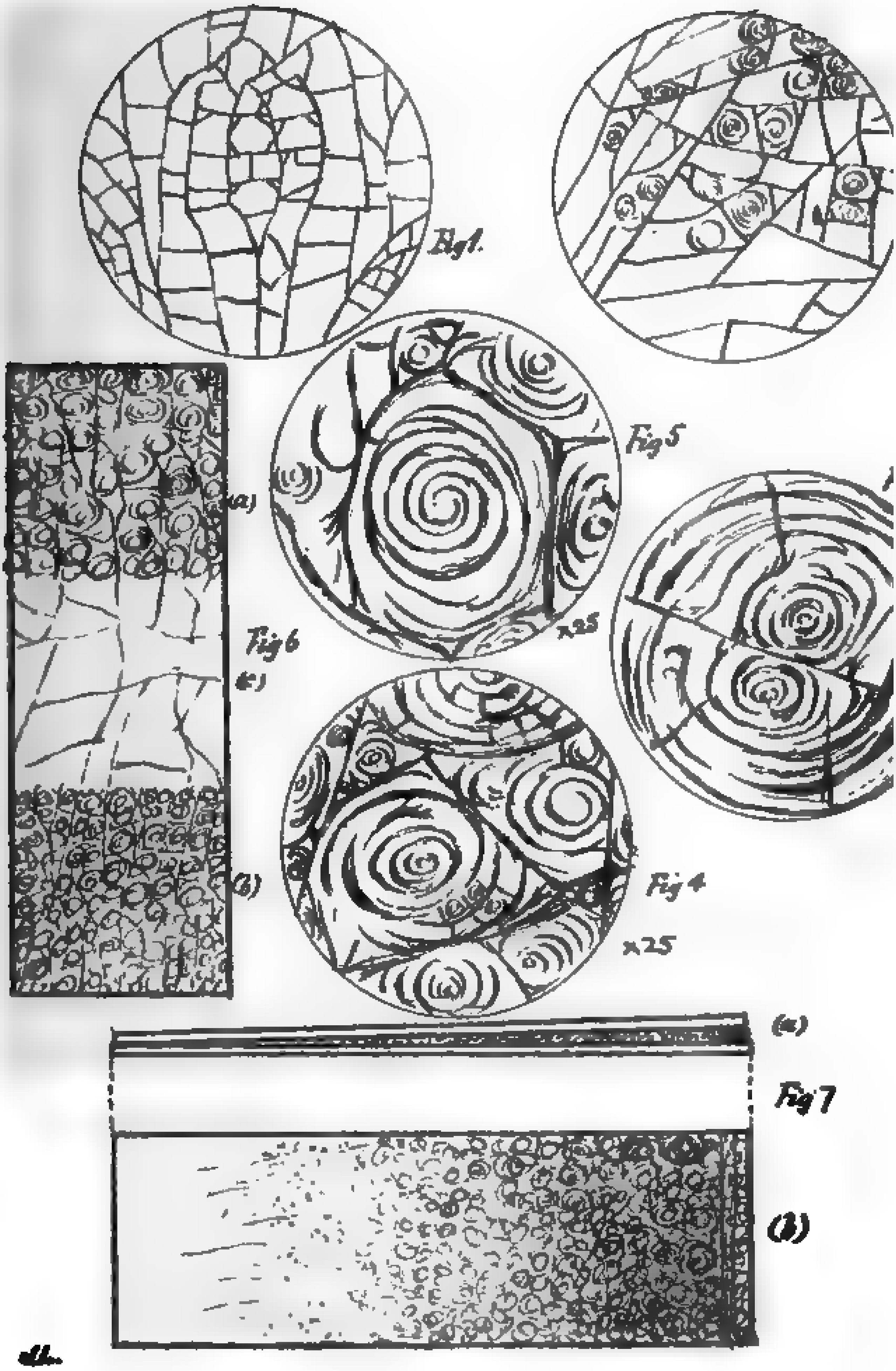
Fig 1.
Fig 5
x25
(a)
Fig 6
(c)
(b)
Fig 4
x25
(a)
Fig 7
(b)

Sometimes a transverse crack may occur in an area after the curved fractures have begun to form. Then we get two series of concentric rings inside one outer ring (Fig. 3). The same feature I have observed in glassy rocks, such as those from Telki Banya, and the devitrified Rhyolite from the Lea Rock, Wrekin.

In some cases the tendency to form the curved cracks is so great that the little triangular patches left by the cracks, which cut off the corners of the primary polygons, are occupied by minute spirals, and we get the appearance of a large spiral, surrounded by four or five smaller ones. The spaces between the curved cracks are sometimes cut by radial fractures, and each space then gets its own system of curves (Fig. 4).

[By means of a magic lantern, provided with horizontal projection apparatus, perlitic structure may be produced, so that a large audience may see the process in actual growth on a screen.]

In order to secure good results each substance must be treated according to its own peculiarities. With *Canada balsam* it is best to get the balsam in the solid state, by driving off the natural solvent over a hot water bath. Then put the roughened glass slip on a thick plate of iron, heated beneath with a spirit lamp or Bunsen gas burner.

When the glass is sufficiently hot hold the solid balsam in the fingers and slightly press it on the hot glass. In this way a good even layer can be obtained without the risk of air bubbles.

Next slide off the glass slip on to a convenient carrier, held on a level with the iron plate, and quickly transfer to a cold, thick iron slab, or plunge into a vessel of cold water. Care must be taken in cooling with water that the glass is not too hot. The iron slab is much

preferable ; the lower plate of a letter copying press answers very well.

The same method does well with *Rosin*, but for the same thickness the cracks are smaller.

Damar is very difficult. It has a high melting point, and forms a stringy, elastic mass when held in the solid state over hot glass. It is best to heat the substance in a porcelain crucible, cool and then reheat to get rid of bubbles, and when melted pour over the hot glass.

Mastic needs to be treated in the same way as Damar.

Copal, also, forms an elastic mass when heated. It is best prepared by repeatedly heating and cooling while on the glass slip.

Shellac only forms on coarsely ground glass, and with a thick layer.

Gum Arabic can only be prepared from a solution of the substance. If a thick solution is placed on a watch glass and gently heated in an oven the mass shrinks on drying, and perlitic cracks are developed. In this case there is no need for roughened glass.

When *Sugar* is gently heated it first melts to an amber coloured liquid. If cooled at this stage it forms a brittle mass, and if rapidly cooled by placing on a cold metal surface, it gives rise to exquisite perlitic structures.

It is best to spread powdered sugar evenly over a heated sheet of rough glass. For lecture purposes sugar is by far the most convenient substance, and is easily manipulated.

The factors which determine the kinds of structure produced are—

(1). *Roughness of surface.*

This introduces a grip, thus rendering differential shrinkage possible. To show that the degree of roughness

influences the result, take a glass slip 3 inches by 1 inch, roughen an inch at one end with very coarse emery. Rub an inch on the other end with fine emery, and leave the central square inch smooth. Then coat over the whole with an even layer of Canada balsam, or rosin, and cool rapidly. [It is easy to test if the film is of even thickness by noticing the reflection of an object from its surface.]

The portion with large pittings will be found to have a coarser development of perlitic structure than the finely ground, and the central part will at most only show a few of the primary cracks (Fig. 6).

(2). *Thickness of Film.* Take two ground glass plates, warm, and evenly coat with Canada balsam. Then put a match stem near the edge of one plate, and invert the other plate so that a wedge-shaped mass of the contracting substance is obtained (Figs. 7a and 7b). On cooling, the perlitic structure is found to be coarser where the film is thick, and it shades off by insensible gradations towards microscopic dimensions where the layer is thin.*

(3). *Degree of Brittleness.* Rosin when just melted and then rapidly cooled seldom gives good results. If, however, the same film be heated and then cooled it becomes more brittle and the result is better. It still improves further with each successive heating and cooling. Other substances do the same.

(4). *Mode of Cooling.* Rapid cooling gives, as a rule, finer examples than slow cooling. It makes a great difference whether the glass or the balsam face is

* The amount of strain produced on the glass plates in this experiment is almost incredible. I put egg albumen between six pairs of circular glass plates, each 3 inches diameter and ⅛ inch thick. In a few days every one of the plates was broken. The contraction of Canada balsam under similar conditions frequently breaks the plates.

immersed in the water first. The very finest examples I have seen were produced on a roughened disc of zinc. The rapid conduction of heat through the zinc seemed to favour the process. Very good results, too, can be obtained on tin plate, roughened by scratching with sand-paper. On mica, too, the structure can be induced. In the case of flexible substances, as mica and tin plate, the finer concentric rings can be induced by mechanical means such as bending, or by a flick of the finger.

It would seem from the above experiments that the primary straight cracks are due to the shrinkage of the mass as a whole, while the curved concentric fractures are confined to shrinkage in the areas cut off by the primary. The spiral arrangement I do not regard as the perfect development of the structure. Careful examination shows that the spiral has not a regular pitch, but shows many inequalities.

The curved cracks can be examined during their formation, and it is seen that they appear alternately on each side of the area. Suppose a crack is formed on the right hand side, then another will appear on the left, but nearer the centre. The next on the right will lie still nearer to the centre, and so on. The right and left curves often overlap. It does sometimes happen that the curves almost meet, and a short loop may join them, giving the appearance of a spiral.

When a film is attached on one side only to glass the finer central curves are near the point of attachment. When the film is held top and bottom by glasses the central curves may alternate between upper and lower attachments, or in some rare cases they are opposite.

We can hardly fail to be struck with the resemblances between this structure so characteristic of the glassy

rocks and others found on a large scale in Basalt and other rocks.

The breaking up into columns may be the expression of the primary cracks. The cup and socket arrangement may be compared with the corner cracks, and the spheroidal weathering of basalt may represent the concentric cracks in the perlitic structure. Greater probability is given to this when we find the spheroidal weathering of basalt does not proceed continuously from the periphery inwards.

There are layers of undecomposed material alternating with decomposed, and there must have been some incipient crack or place of weakness, corresponding to the concentric curves in perlitic structure.

EXPLANATION OF PLATE.

Fig. 1.—Primary and secondary cracks.

Canada Balsam on Zinc.

[The concentric cracks have been omitted].

Fig. 2.—Primary and secondary, and a few concentric cracks.

Mastic on roughened glass.

Fig. 3.—Copal on roughened glass.

Shows two sides of concentric fractures formed inside one system of cracks.

Fig. 4.—Rosin on roughened glass.

Concentric cracks formed in angles cut off by secondary cracks, and in spaces cut off by radial fractures.

Fig. 5.—Copal on roughened glass.

Double spiral arrangement.

EXPLANATION OF PLATE—CONTINUED.

FIG. 6.—Canada Balsam on glass, with varying degrees of roughness of surface:—

(*a*) Rubbed with coarse emery.

(*b*) Rubbed with fine emery.

(*c*) Smooth glass.

FIG. 7.—Canada Balsam on roughened glass.

(*a*) Elevation to show wedge-shaped mass of balsam.

(*b*) Plan, shows thickness of film determines coarseness of structure.

ON THE OCCURRENCE OF PHOSPHATE OF IRON COATING SAND GRAINS AT TRANMERE.

By W. MAWBY.

(Read 12th December, 1893.)

ALL geologists are familiar with the red and brown colours of the local Triassic Sandstones, which so seldom present any other tint than that caused by the iron oxides so generally prevalent, which vary only in proportion to the amount of iron present in any given spot. When any other colour occurs it is the more noticeable, especially so when the not very brilliant commonplace tones are replaced by those of a brilliant hue. There exists at the present time a variation of this kind in the neighbourhood of Higher Tranmere,

where a sandstone wall of the familiar yellow shade is coated along lines, and in isolated patches, with a rich blue.

The question immediately arises, "What is the cause of the change?" A chemical analysis, kindly made for me by Mr. Lomas, proves it to be due to the presence of phosphoric acid in the form of phosphate of iron, combined with a trace of phosphate of magnesium. As this is not a very common phenomenon, a few further remarks upon its occurrence may not prove uninteresting.

Phosphorus is never found native, but is met with as calcium phosphate in rocks, from the disintegration of which it passes into the soil, being soluble in water containing carbonic acid or other salts, and is extracted by plants in sufficient quantity to support the various animals which feed upon them.

The most important of the oxides of phosphorus is that which unites with water to form phosphoric acid ($P_2 O_5$). In this form it is universally diffused throughout the three great kingdoms of Nature, pervading both living and inanimate matter. It is found in rocks of every age as calcium phosphate, either distributed throughout the mass of a rock in chemical combination, as a pure mineral collected into cracks and cavities, or as forming a large portion of fossil remains. This is perhaps the most important phosphate, and is sometimes used as an artificial manure. As phosphate of iron it is probably familiar to most of the members of this Society, from its presence in the partially submerged peat beds existing around these coasts. This is the hydrated and earthy form generally known as vivianite, and is sometimes used as a pigment. Vivianite also appears

in mineral veins and in some lavas. Among the mineral constituents necessary to the support of vegetable life phosphoric acid is of great importance, but as it exists in only a limited degree in the soil it must be supplied by means of manures. For this purpose fish and other marine organisms are highly esteemed on account of the amount of phosphorus they contain. To revert to the first mentioned deposit. This occurs on a wall at the top of the Prenton Road, and enclosing land some four feet higher than the road. This land being used as a kitchen garden has been heavily dressed with pig-sty refuse, saturated with urine, and contains moreover a large amount of decaying vegetable matter. This material seems to be the source of the phosphorus which has been deposited along the mortar joints, and has extended in some places quite four inches over the face of the wall. It does not penetrate to any depth, and is thickest close to the mortar joints.

NOTES ON SHELL BRECCIA DREDGED OFF THE COAST OF THE ISLE OF MAN; AND ON THE SOURCE OF THE CARBONATE OF LIME OF THE SHELLS OF MARINE ORGANISMS.

By E. Dickson, F.G.S., and P. Holland, F. Inst. C.

(*Read 13th February, 1894*).

This specimen, which was very kindly lent to us by Mr. Leicester, was originally dredged up about 25 miles South-west of the Isle of Man, in about 25 fathoms of water. It consists of shells and shell-fragments in a

sandy matrix, cemented together by carbonate of lime. The shells, we are informed, are recent shallow water shells, and the following list of shells in this specimen has been supplied by Mr. Leicester and Dr. Chaster—*Lucina borealis*, *Cardium echinatum*, *Pecten opercularis*, *Cyprina islandica*, *Venus galina*, *Venus ovata*, *Nucula nucleus*, *Turritella terebra*. We understand that, from time to time, quantities of this Shell Breccia are dredged in the locality mentioned, which suggests the existence of a considerable deposit formed within comparatively recent times, or possibly now in course of formation.

Thinking it might interest the Society to have particulars of the grey sandy material that forms the matrix in which the shells are embedded, an analysis was made of this portion of the concretion. It gave the following numbers—

Matter insoluble in HCL—Sand	66·19
Silicic Acid	0·25
Carbonate of Lime	31·57
Carbonate of Magnesia traces, Alumina and Oxide of Iron	1·04
	99·05

In making the analysis, care was taken to exclude shell-fragments from the portion selected, which, after weighing, was dissolved in hot dilute hydrochloric acid. There was no trituration of the substance, as this would have destroyed the original forms of what remained after the acid treatment. The residue, it will be observed, is 66 per cent. of the whole, and under the microscope with moderate magnification is seen to consist of sub-angular grains of quartz and other rock-forming minerals, with here and there an occasional reddish spherical grain, resembling what is often met with in dust from marine boiler flues. In addition to sub-angular quartz grains we noticed some amorphous

silica, which in drying the residue had collected in small flakes, easily distinguishable from grains of sand, and readily breaking up when touched with a needle point.

It is highly probable that some silicification of the lime had taken place—as is the case in old mortar—and that the flakes were silica, which the acid treatment had separated therefrom. We failed to find in the residue any siliceous skeletons of diatoms.

Deposits like the one now under consideration are not very uncommon, a similar rock-forming process if we may so term it, taking place on the Cornish Coast, near Padstow. On the shore of the Clyde too, below Dumbarton, a considerable extent of calcareous sandstone occurs with recent shells. Some years ago one of us observed on the Mediterranean Coast, near Cannes and Nice, a recent deposit like that on the Clyde. The cementation of the material forming these deposits may, perhaps be due to carbonate of lime, for along the Coast of the Riviera and on the North Coast of Italy, there are limestone hills much fissured, which almost abut the water's edge. Fresh water collecting in the fissures would be enabled by vertical pressure to make outlets within the marine area. A highly calcareous spring such as this would undoubtedly be, could by depositing lime carbonate, cement together detrital débris and form a bed similar to that on the shore at Cannes.

We are inclined to the opinion that the concretion from the Isle of Man owes its origin to calcareous springs, the matrix containing the shells being made up of sand of the sea bottom, cemented together by lime carbonate from the springs; there is a considerable area of Carboniferous Limestone on the south coast of the island,

which may extend below sea level. Should this be so, the formation could hardly be free from fissures, whence lime bearing water would be discharged. It would be of interest to learn if concretions like the one in question occur at more than one locality off the Isle of Man Coast.

Our explanation of the genesis of the concretion is open to the objection that water of a calcareous spring issuing on a sea bed would become at once diffused, whereby deposition of lime carbonate on surrounding objects could not take place. In reply it may be said that the water of the spring on emerging will probably give up its excess of carbonic acid, either to highly basic matter as shell débris on the sea bed or to marine confervæ. A removal of carbonic acid by such agents would cause deposition of lime carbonate. Messrs. Ludwig and Theobald,* who give detailed analyses of Calcareous Sinter from the conduits of the brine spring at Nauheim, a spring holding lime in solution, consider the separation of this sinter, which contains upwards of 90 per cent. of lime carbonate, to be a function of confervoid growth. The confervæ it would appear, by extracting the free carbonic acid from the brine wherewith to build up their own structure, cause deposition of lime carbonate, for it is the free carbonic acid in the brine that enables the latter to hold the lime in solution. It would not seem improbable that marine confervæ should act in the same way when growing in a medium not very unlike the brine at Nauheim, which a mixture of water of the supposed spring with sea water would be.

The study of the concretion has led us to consider the source of and to remark on the lime carbonate, the chief part of the shells of the marine organisms. Rivers largely endow the ocean with lime salts, the amount

* Poggendorff's Annalen, vol. 87, p. 91.

contributed by a particular river naturally depending on the volume of water and on the composition of the strata through which the river and its tributaries have cut their channels. The mean figure for lime carbonate in the water of 30 European rivers we find to be about 10·8 parts per 100,000. Though the annual addition of lime carbonate to the sea by the rivers of the world must be enormous, it is, nevertheless, the fact that clear sea water is comparatively free from it. English Channel water contains only 3·3 parts per 100,000, and this small amount is found chiefly near the coasts. What, it may be asked, becomes of the lime that rivers bring to the sea? Does the supply just meet the demand of marine life, or does a considerable precipitation of some insoluble and therefore unavailable lime compound take place on the marine floor? Analyses of clear sea water from the English Channel record the fact, that although poor in carbonate it is rich in sulphate of lime, the amount being 140·6 parts per 100,000. This comparatively high figure would almost suggest chemical processes at work in the ocean by which carbonate becomes sulphate of lime. One such process would be the neutralization by lime carbonate of sulphurous exhalations from submarine volcanic vents. It is worthy of note in this connection that J. Davy* found "scarcely a trace of lime carbonate in the neighbourhood of the volcanic island of Fayal," an observation supporting the inference that near Fayal volcanic gases may possibly convert the lime carbonate into the sulphate. That sulphurous acid in volcanic gases will be neutralized by carbonate of lime, does not admit of any doubt; were this not so, sea water should in time have an acid and not the alkaline reaction it is well-known to possess.

*Edin. New Phil. Journal, vol. 47, p. 320.

The high ratio of lime sulphate to carbonate in sea-water could also be set down to the fact that being less serviceable than carbonate to the needs of marine life, it would tend to accumulate were processes not in operation to prevent such accumulation.

As it seemed desirable to learn something of the lime salts that compose a typical marine shell, we selected the internal layers of the shell of the oyster, rejecting stained and encrusted portions. Fragments of shell of twelve fresh oysters were set apart, ground to fine powder in an agate mortar, and the powder dried at 212° Fahrenheit.

Two Analyses were made of the powder. The figures below are the mean:

$CaCO_3$	97·670
$CaSO_4$	0·975†
$MgCO_3$	0·126
$Fe_2O_3 + Al_2O_3$	0·120
P_2O_5	nil
MnO	trace
SiO_2	0·180
Moisture at 212° F	0·250
Organic Matter, containing Nitrogen, not estimated	0·679
	100·000

Total of CaO	55·10 per cent.
„ CO_2	43·08 „
„ MgO	00·06 „

It would appear that the oyster, though building its shell mainly of lime carbonate, makes use also of the sulphate to a slight extent. Other testaceous molluscs may employ it more largely.

Oyster shells, as is well known, form large beds, whence it may be inferred the shell matter must present

† In Shell from another purchase of Oysters the $CaSO_4$ was 1·158 per cent. Its presence cannot be regarded as accidental.

considerable resistance to the solvent effect of carbonic acid, by whose agency re-solution of shells in sea water is considered to take place. Bischof considers this resistance to solution to depend on the protection afforded by the organic material of the shell, and shows by experiment with carbonic acid and water that lamina from the interior of the shells are less attacked than is the case with chips from the exterior, where presumably the organic material has in some measure decayed and disappeared.

In order to compare the relative solubility of our shell matter with chalk, we took equal weights of each in powder and exposed them to the action of water and CO_2 in bottles under a pressure of $1\frac{3}{4}$ lbs. to the square inch for 30 days. The volume of water was 250 C.C., and the weights of shell and chalk 2 grammes, in each of the four experiments. The bottles containing the chalk and the shell were gently shaken from time to time. On detaching the CO_2 generator at the conclusion of the experiment gas escaped from all the bottles, showing that excess of carbonic acid was present throughout the operation. The undissolved chalk and shell were collected on filters, dried, and re-weighed.

Experiment.	Shell.	Chalk.
1.—Dissolved by CO_2	10·95	9·30 per cent.
2.— ,, ...	10·73	9·66 ,,
Mean	10·84	9·48 ,,

These experiments show that powdered chalk under precisely similar conditions of treatment as regards duration of action and volume of solvent, withstands the effect of carbonic acid in a greater degree than does powdered shell as less dissolved. From the ascertained composition of the shell-powder it would be expected to yield slightly more matter to CO_2 and water than would chalk, inasmuch as the shell contains lime

sulphate, which even water *alone* could hardly fail to extract (lime sulphate was easily detected in the filtrates from the shell experiments). If, then, allowance be made for the lime sulphate, and 0·975 per cent.—the amount found in the shell—be deducted from 10·84, we still get 9·865 per cent. for dissolved lime carbonate in the form of shell, as against 9·48 per cent. in the form of chalk; thus showing the shell to be the more soluble of the two, under the conditions in which the two sets of experiments were made. With dead shell, *minus* its organic matter, the resistance to solution will probably be the same as for chalk.

NOTES ON THE SUBMARINE DEPOSITS OF THE IRISH SEA.

By W. A. Herdman, D.Sc., F.R.S.

(Read 13th February, 1894).

When, in 1885, the Liverpool Marine Biology Committee commenced their dredging investigations into the fauna of Liverpool Bay, and the neighbouring parts of the Irish Sea, I suggested, as a part of the programme of work, that it would be of some importance to examine and map out the deposits met with in the various parts of the area, to correlate them when possible with the rocks forming the neighbouring coasts, and to determine to what extent any relation exists between the nature of the bottom and the assemblage of animals living on it. During the past nine years, although the greater part of the attention of the Committee on the dredging expeditions has been taken up with the examination of the animals obtained, still the nature of the bottom has

been usually noted, and I have from time to time inserted on a map kept for the purpose the distribution of the sand, mud, and other deposits met with. This map I hope to publish, with a description, when more complete; but in the meantime the following notes on some of our results may be of interest to geologists, and will give an opportunity for criticism of our methods and chief conclusions from the geological point of view:—

1. The most extensive shallow water deposit is sand. In most localities along the coast of Lancashire, Cheshire, and North Wales, from the sea shore out to the 10-fathom contour the bottom is formed of more or less pure quartz sand. Occasionally in spots there are local patches of stones, of shells, or of mud; but these can generally be accounted for by tidal or estuarine currents, by the entrance of fresh water streams carrying down alluvium, or by the presence of littoral or sub-littoral boulder clay. These spots are all, however, of small area, and the great extent of the bottom down to 10 fathoms is sand.

2. Further out, however, between 10 and 20 fathoms, the sand becomes greatly mixed with mud, and much diversified by large tracts of shelly deposits, or by patches of gravel, and the fauna on the bottom also becomes much more abundant. In some spots, at about 20 fathoms, it is made up over considerable areas almost entirely of ophiuroids (*Ophiocoma nigra* and *Ophiothrix fragilis*) which fill the dredge haul after haul. At two localities off the Isle of Man, viz., along the east coast from Clay Head to St. Ann's Head, and off the west coast between Contrary Head and Niarbyl, at depths between 10 and 20 fathoms, are great nullipore deposits formed of *Melobesia* and *Lithothamnion*, which have a most characteristic appearance, smell, and fauna.

This area of the sea-bottom, from 10 to 20 fathoms, extends across from the north of Lancashire to the Isle of Man, so that opposite Barrow, for example, there is a wide extent of about 50 miles in length of sea-floor at depths of not more than 15 or 16 fathoms. The Isle of Man is connected with England by this plateau, and is separated from Ireland by deep water.

3. Depths of over 20 fathoms are only found to the west, north, and south of the Isle of Man; and depths of from 20 to 50 fathoms give us the most varied bottom deposits and the richest fauna. As a rule the sand is more or less mixed with mud, and as the bottom goes deeper the amount of mud gets greater. When there is a considerable admixture of mud with coarse sand, that forms what is known to the trawlers as a "reamy" bottom, and that is the ground upon which the sole and some other fish are generally found spawning.

Shells and other hard parts of animals play an important part in the deposits at depths of about 20 fathoms and upwards. In places the dredge comes up filled with Pecten shells, dead and alive, chiefly *P. opercularis* and *P. maximus*. At other places the deposit is practically composed of the shells of *Pectunculus glycimeris*. These and other shell beds form a rich collecting ground to the naturalist, as they support an abundant and varied fauna. Zoophytes and polyzoa are attached to the shells, and these serve as shelter for nudibranchs and other small mollusca, worms, and ascidians. On the whole the heterogeneous deposits support a richer fauna than do the homogeneous deposits, such as sand or mud, and it is chiefly in the zone of depth we are now considering that the heterogeneous deposits occur.

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4. The depths over 50 fathoms contain a pure dark bluish grey mud which is very tenacious, and sets when dried into a firm clay. This is abominable stuff to dredge in and to work with on deck. It clings to everything that touches it: it is almost impossible to see what is in it, and to get the animals out of it uninjured; it is too solid for the sieves, and the hose can be played upon masses of it almost indefinitely without dissolving it. The fauna of this zone is, in our district, quite peculiar and characteristic. It its shallower parts, about 50 fathoms, it contains great numbers of living and dead *Turritella terebra*, upon many of which are attached one, two, or three specimens of the little red anemone *Sagartia Herdmani*, Haddon. In its deeper parts, up to 80 fathoms, are found *Calocaris Macandreæ*, *Hyalinœcia tubicola*, a small *Lumbriconcreis*, *Panthalis Oerstedi*, *Lipobranchius Jeffreysii*, *Brissopsis lyrifera*, *Amphiura Chiajii*, and *Isocardia cor*.

These are the leading conclusions we have come to so far in regard to the *distribution* of submarine deposits in our area. Two further questions now present themselves: first, the biological one—the effect upon the fauna; and secondly, the geological one—the origin of the deposits. In regard to the importance of the nature of the bottom to the animals living upon it there can be no doubt. Probably the nature of the deposit is the most important of the various factors that determine the distribution of animals over the sea-bottom within one zoological area. It is certainly more important than mere depth; a muddy bottom will support a similar fauna at 10 fathoms in one place, and at 50 fathoms in another. Probably the most important influence in the environment of a lower animal is its food, and once beyond the narrow sub-littoral zone in which algæ flourish—and to which,

of course, certain phytivorous animals must be restricted—it is probably chiefly the nature of the bottom which determines the food. Many animals feed upon the deposit, others browse upon the polyzoa and zoophytes which can only attach themselves and grow where there are sufficiently large objects, such as shell valves, from which they can get the necessary stability; while others, again, feed upon their neighbours, which subsist on the deposit, or are attracted by the zoophytes, &c. The same locality may vary so much from time to time in the temperature, the salinity, and the transparency of the water, that it is probable that none of these factors—so long as the variations do not exceed certain limits have so much influence upon the fauna as the nature of the deposit has. It is therefore quite to be expected that the fauna should vary from place to place with the nature of the bottom, and that is what we have observed frequently in our work round the Isle of Man. In practically the same water, identical in temperature, salinity, and transparency, at the same depth, with, so far as one can see, all the other surrounding conditions the same, the fauna varies from place to place with changes in the bottom—mud, sand, nullipores, and shell beds, all have their characteristic assemblages of animals.

As to the further, and very important question of the origin of the deposits, that is to a great extent a purely geological inquiry, and one which cannot, until we have accumulated a much larger series of observations, be fully discussed; but there are a few matters which may be briefly pointed out as giving some idea of the range and bearing of the question.

1. It is necessary to make a most careful examination of the deposits. For example, all muds are not the same in origin. A deposit of mud may be due to the

presence of an eddy or a sheltered corner in which the finer particles suspended in the water are able to sink, or it may be due to the wearing away of a limestone beach, or to quantities of alluvium brought down by a stream from the land, or to the presence of a submerged bed of boulder clay, or, finally, in some places to the sewage and refuse from coast towns.

2. I have kept in view the possibility of some correlation between the geological formations along the beach and the submarine deposits lying off the shore. There is no doubt that the nature of the rock forming the shore has a great influence upon the marine fauna, and has sometimes *some* effect upon the neighbouring deposits. For example, the contrast between the deposits lying off the two prominent headlands, the Great Orme, in North Wales, and Bradda Head, in the Isle of Man, is well marked. The Great Orme is composed of mountain limestone, and the result of its weathering and erosion is that large blocks are found lying scattered outside its base on the fine sand; but there is no deposit of smaller stones, gravel, and resulting sand farther out, probably because in the wearing of the rock and the large detached blocks by the sea a great deal is removed in solution and the rest in suspension as very fine mud—this we have found to be the case round Puffin Island, which is also mountain limestone. Bradda Head, on the other hand, is a schistose metamorphic silurian rock, which breaks up into large fragments, and these into smaller, and so forms deposits of dark slatey more or less angular gravel, and then very coarse sand, extending for some way out from the foot of the cliff.

The influence of the shore rocks upon the littoral fauna is an important subject upon which we have

accumulated some observations; but the matter requires further work and detailed discussion, and must be left over for a future report.

3. Probably the great bulk of the silicious sand which forms so large a part of the floor of our sea is derived proximately — whatever may have been its ultimate source*—from the great deposits of drift which were formed in the neighbourhood during the Glacial period, and large tracts of which may since have been broken up by the sea.

4. As examples of a few peculiar and specially noteworthy deposits which are not simply 'terrigenous' in their origin, the following may be mentioned:—

South-east of the Calf Sound, about two miles out, at a depth of 20 fathoms, there is a white shelly sand which seems to be almost wholly composed of animal remains. There are broken fragments of the lamellibranchs *Pecten*, *Anomia*, *Pectunculus*, *Mactra*, *Venus*, and *Mytilus*, of the gastropods *Cypræa*, *Buccinum*, *Emarginula*, *Purpura*, and *Trochus*, of various calcareous polyzoa such as *Cellaria fistulosa*, *Cellepora pumicosa*, and lepralids, of *Balanus* and *Serpula*, and of various echinoderm plates and spines, and the whole shells of *Echinocyamus pusillus*. The deposit, when it comes up in the dredge, is of a gleaming whiteness, and has a very characteristic appearance. Such a deposit as this would form a rock almost wholly made up of fossils, and might compare well with some Tertiary fossiliferous deposits, such as the Coralline Crag.

A little further north, along the east coast of the Isle of Man, at about a corresponding depth and distance from land, we meet with a purely vegetal deposit formed

* Probably, to a great extent, Triassic sandstones.

of the nullipores *Lithothamnion* and *Melobesia*. On the other side of the island, again, between Port Erin and the Calf, at a depth of 18 fathoms, there is a tract of sea-bottom which, when brought up on deck, looks at the first glance like a peculiarly fibrous sand, but a closer examination shows that it is entirely composed of the comminuted plates, and especially the spines of echinids, chiefly *Spatangus*. I do not remember to have met with a reference to material such as this either amongst recent or fossil deposits.

The variety that is noticed in submarine deposits round the Isle of Man, from depths of 15 to 35 fathoms, as brought up in the dredge is very striking. It is remarkable how differing proportions in the mixtures of sand, gravel, and shells give rise to very different colours and general appearance in the mass. As seen when tumbled out of the dredge on to the deck, some deposits are white, some yellow, some grey, some reddish, of various tints from pink to ruddy brown, and others darker, of all shades of brown and dark grey. It is curious how, even in a composite deposit made up of many different constituents, there is usually a prevailing tint; for example, the bottom at one spot, although composed of mud, sand, nullipores, shells, and stones, is distinctly of a rich ruddy brown tint. The importance of this presence of prevailing colours in the various submarine deposits is obvious in its bearing upon the colours and habits of animals.

Another very remarkable sea-bottom is one which takes the form of irregular calcareous masses, cementing together the dead shells and sand grains which are lying on the bottom, and making lumps like 'clinkers.' Hence the spot where it is found is called by the trawlers the 'Blacksmith's Shop.' It is about 25 miles S.S.W. of

the Calf of Man, in ordinary clear weather the Chicken Rock Lighthouse just dipping and the stack at Holyhead just rising above the water, and the depth is about 25 fathoms. We have also heard of a similar bottom of cemented shells between Ramsey and St. Bees' Head. Mr. Leicester has found the following shells in the concretions:—*Pecten opercularis*, *Cyprina islandica*, *Venus lincta*, *Cardium echinatum*, *Nucula nucleus*, *Scrobicularia alba*, *Lucina borealis*, and *Turritella terebra*. There is a fine lump of this deposit in the Biological Station at Port Erin, and another piece has been sent to the Jermyn Street Museum in London. Mr. W. W. Watts, of the Geological Survey, has made a careful examination by thin sections of the latter specimen, and he has kindly sent me the following notes in regard to it:—"The microscopic examination shows that it is practically a fine grained grit made up of the usual constituents of fragmental rocks cemented together, the cement being in greater quantity than the grains. These grains are chiefly chips of quartz, but I have also seen microcline, orthoclase felspar, plagioclase felspar, brown mica, a few grains of glauconite, and green and brown pseudomorphs, probably after grains of some ferro-magnesian mineral like augite, hornblende, or even possibly olivine—which it is impossible now to say, but I think most probably hornblende. There are one or two opaque grains, and several clear grains containing a good deal of minute magnetite. The grains vary in size within small limits, the largest I have measured is 0·02 inch and the smallest 0·002 inch, but the average size would be about 0·004—0·005 inch in longest diameter. They are therefore minute grains, and, as might be expected, extremely angular, not one in a hundred showing rounded outlines. They are chiefly such grains as would

come from the denudation of granitic rocks or sediments derived from them.

"The cement is carbonate of lime, with a small impurity of carbonate of iron, present chiefly in certain layers but not there in any considerable quantity. The cement is clearly crystalline in immediate contact with the grains, and also where lining cracks and cavities. Elsewhere it is more opaque, and less conspicuously crystalline. The section cuts across numerous shell fragments and a few polyzoa, and where there are any hollow structures, as in the inside of lamellibranchs or gastropods, they are filled up with a substance indistinguishable from the bulk of the concretion.

"The specimen shows no particular reason for the local deposit of cement, and the other constituents are doubtless the ordinary materials of the sea-bed. I cannot find any evidence that the cementing is due to any organic agency, and the thoroughly well-developed crystals of carbonate of lime quite agree with this. It may be that the Carboniferous limestone crops out on the sea-bottom under the deposit, and if so, there would very likely be submarine springs laden with carbonate of lime which might be precipitated there under less pressure or local loss of carbonic acid. It may be added that Mr. Clement Reid could not see in the specimen any identifiable shells of other than recent age."

Another possible explanation is that the smaller calcareous particles on the bottom have been dissolved in the sea-water and then re-deposited so as to cement together the larger shells and the sand grains.

Sample bags of all the more important submarine deposits we have come upon have been sent, at Sir Archibald Geikie's request, to the Museum of the Geological Survey in Jermyn Street. They are being

examined there by Mr. Clement Reid, F.G.S., who writes the following preliminary note in regard to them:—

"On comparing these samples with British deposits of Tertiary date, one finds a marked difference in lithological character. Dredgings from the Irish Sea, and also from the North Sea, are characterised by a much coarser and more gravelly texture than one would expect at such depths—coarser, in fact than one finds in Pliocene deposits, yielding a similar fauna, indicating similar or even smaller depths. A glance at these dredgings shows the reason of this, for they are largely composed of unworn, or little worn, fragments of rock, often entirely incrusted by organic growth. The stones evidently have not been transported far by water, or they would be well rounded, like the pebbles found in our Eocene beds. The incrusting organisms show also that the fragments have lain undisturbed on the sea-bed, yet they have often been derived from far-distant sources. Though no Glacial striæ were observed, and no undoubted sub-fossil arctic shells have yet been found at these localities, yet there seems little doubt that the bulk of the material on the sea-bottom over this area has been derived from the breaking up of pre-existing Glacial deposits. This may occur at a depth of several fathoms through the gradual washing away of the muddy and sandy matrix of a boulder clay or Glacial gravel. Coarse gravel is thus caused to accumulate at a spot where the currents may be too feeble to transport anything but sand.

"This submarine origin of angular gravel deposits should not be forgotten, for it affects the lithological character of the sea-bottom over most of the area which was formerly glaciated, even as far South as Cornwall. On the other hand, it does not affect, except to a small extent, the sea-bed beyond the former limit of the ice,

and it does not affect pre-Glacial deposits. Thus we must always expect to find at similar depths the same fauna associated with deposits of finer texture as soon as we leave the glaciated area, or when we go back into Tertiary times.

"It is also worth noting that the occurrence of a stony bottom at twenty or thirty fathoms—where normally there would be no deposit coarser than sand—will probably lead to a disproportionate increase of all incrusting organisms, and of all organisms needing a solid base. This has certainly taken place, as anyone studying our shoal-water Tertiary deposits will have observed. They contain few stones, and though each stone or dead shell may be covered with incrusting organisms, yet the relative proportion of these to the free forms is far smaller than seems commonly to be the case in the seas that now wash our shores. The sole exception to this rule among the British Tertiary strata is found in the Coralline Crag, in which the contemporaneous consolidation of the limestone was sufficient to provide the necessary solid base for the incrusting and fixed organisms so abundant in that deposit."

In conclusion, it seems to me that this investigation of our modern submarine deposits, their distribution, nature, origin, and associated fauna, has geological applications, and that our results may be of some importance to palæontologists, *e.g.*, in aiding them to determine the conditions under which the fauna of a particular horizon probably existed in the past.

THE DUBLIN AND WICKLOW SHELLY-DRIFT.

By T. Mellard Reade, C.E., F.G.S., F.R.I.B.A.

(Read 13th March, 1894).

The Glacial Drift of the Sister Isle is hardly so well known to English Geologists as it should be. Speaking from my own experience, it will amply repay the student who can devote his time to its elucidation. In pursuit of my studies of the High-level shelly-sands and gravels, I last summer spent a fortnight in examining the shelly-drift deposits in the neighbourhood of Dublin, and the northern part of County Wicklow. With the cordial assistance of the Rev. Maxwell Close, who has done so much to make the district famous in the eyes of those who interest themselves in the great problem of the Glacial Period, I was soon introduced to the classical drift sections, and my self-imposed pleasant task made much easier of accomplishment.

To a Geologist familiar with the High and Low-level drifts of England and Wales, the most striking feature in these Dublin and Wicklow deposits is their continuity from low to high levels, and the great bulk of the High-level drift. The next surprise is the extraordinary prevalence of limestone gravel, reaching from sea-level to an elevation of 1,200 ft. and more, and lying to a large extent upon a bottom-rock of granite. Throughout almost all of the drift, in greater or less proportion, a careful search will be rewarded with the discovery of shell fragments of marine origin. In some, no doubt, the search may be severe and long, but still, little of the drift is absolutely barren. Sufficient may be found to swear to, that is to say, to render it certain that the elevated drift all belongs to the High-level shelly type.

Following the system pursued by me in the monograph on the "Drift Beds of the Moel Tryfaen Area of the North Wales Coast,"* I will begin with the Drifts of the coast, and trace them up to the highest levels, although not with the same detail, for it is unnecessary to do that in every case, such minutiæ being only required to establish principles which, once understood, are readily applicable to other localities.

The Coast Sections.

Hill of Howth.—Commencing at the north, at the Hill of Howth (sheet 112, Ordnance Survey), we here see a fine development of sands and gravels reaching from Howth to the Bailey Light House. This fine headland of much contorted Cambrian schist and quartzites is practically an island attached to the mainland by a bank of blown sand, now gradually becoming covered with residences. It is about two miles in diameter, and rises to a height of 560 feet above O. D. The coast on the east side is very precipitous. Against the steep rocky slopes, and partly upon them, lies a drift of sand and gravel, containing bands and strings of gravel and shingle. Shell fragments are quite common. To the north limestone preponderates, but mixed with erratic granites. As we proceed southward we perceive that the sea has in many places cut away the drift and exposed rocky cliffs. The drift, in such cases, lies on the rocky slope many feet above the sea at the base, and rises in one place to a height of about 300 feet above the sea level. The drift now begins to have a large proportion of Howth schist in it, though limestone gravel still preponderates, and shell fragments are frequent. I took out a granite boulder with black mica,

*Proc. of L'pool Geo. Soc., Session 1892-93.

different to any of the granite we saw at Glencullen. The limestone gravel is often striated. I observed a light gray limestone boulder five feet across, and well striated.

Near to Bailey Lighthouse the sandy drift occurs high up on the top of the cliffs.

The Bailey Lighthouse is a sort of monument to the drift, for it is built upon a projecting spur of rock, capped with drift. I had not time to examine the south coast of the Hill of Howth, but there is ample evidence in the two miles of east coast that these stratified drifts have formerly extended considerably out to seawards, and have been swept away by the waves. What we see now is but a remnant of what formerly existed. It seems, in many cases, quite remarkable how the drift clings to the steep slopes on which it often lies.—(*See Plate* 1.)

The sands when microscopically examined are very like the Nevin and Tryfaen sands—they are full of shell fragments—mostly well worn and in all stages of decay—together with well rounded shelly grains. The quartzose grains greatly preponderate, and are as a rule well rounded, some extremely so. I sifted this drift with riddles of $\frac{1}{20}$, $\frac{1}{40}$, and $\frac{1}{100}$ inch mesh. In the grains from the $\frac{1}{100}$ mesh the shell fragments often approach the spherical. The sand is clean. There are well-worn limestone pebbles amongst the common material—one the size of a small bean was striated. The local materials do not preponderate here as they do in the Eskers and High-level gravels of the neighbourhood. One small pinch of sand contains at least half a dozen shell fragments, often more. The sands are of a distinctly marine character. The quartzose sand has, I believe, come from the sea bottom, and littoral, where it has been working about by tides, winds, and currents

for ages. The Hill of Howth is an exposed sea-girt rock. Further inland highly polished quartz grains are met with as erratics in the drift, but here they form a large bulk of the material.

The few shell fragments, which my son Aleyn and I collected, are, as determined by Mr. R. D. Darbishire :—

(Whole).—*Nasso incrassata, Patella vulgata.*

(Frag.)—Pillar of *Buccinum, Turritella terebra, Astarte, Cyprina, Mya, Cardium edule, Ostrea, Corbula nucleus, Leda pernula.*

One mile on the road from Howth to Sutton boulder clay is seen resting on Carboniferous limestone, and capped with gravelly clay and loam. The boulder clay is full of limestone, grits (Silurian ?), and quartz pebbles.

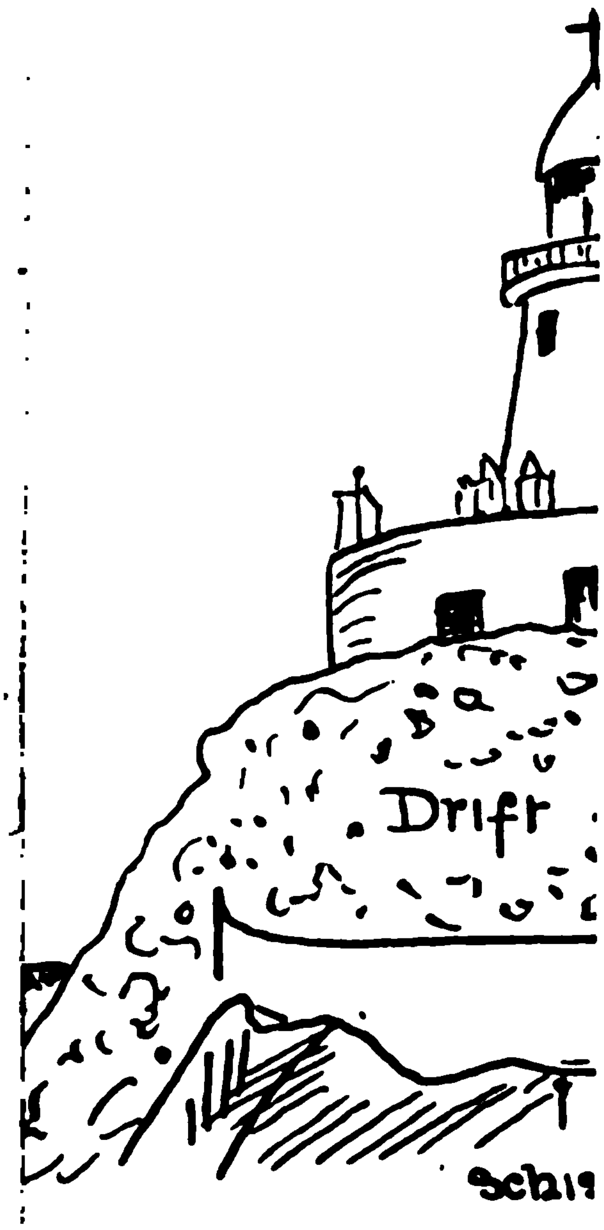
The Hill of Howth is easily reached from Dublin by the railway, and is well worth a visit.

KILLINEY.—Killiney Bay is a very interesting spot, both for the peculiar charms of its scenery, and for the cliffs of drift fringing its shores.

The section I exhibit extends from a few hundred yards north of the footway from Ballybrack station to the shore, to the Martello Tower, about half way to Bray. —(*Plate 2 is a portion of this Section.*)

It is an excellent illustration of the way boulder clay, sands, and gravels—boulder gravels and stratified sands occur in relation to each other, exhibiting arched stratification, oblique bedding, horizontal bedding, truncation of beds, and contorted bands of sand.

The gravels and boulders consist mostly of limestone and granite, felstone, sandstone, flints, and apparently a little hard chalk. Shells and shell fragments occur throughout the whole section, both in boulder clay, and sands and gravels, excepting near to Ballybrack Station,


Drift

where the gravels are very hard, being cemented together, and standing vertically. This piece stands as a wall between the railway cutting and the shore. Almost every phase of glacial drift, except pure Till, can be seen in this section. The fragments taken out of the drift were *Astarte arctica*, *A. sulcata*, *Cardium edule*, *Mya truncata?* *Tellina balthica*, and indeterminable fragments. Very little search was made for them, my time being occupied with the section. Mr. Lloyd Praeger gives the following list of shells found by him and Prof. Sollas in the Killiney Drift* :—

Boulder clay, *Ostrea edulis*, *Mytilus edulis*, *M. modiolus*, *Leda pernula*, *Lucina borealis*, *Cardium edule*, *Cardium echinatum*, *Cyprina Islandica*, *Astarte sulcata* *Astarte compressa*, *var striata*, *Tapes aureus?* *Tellina balthica*, *Mactra subtruncata*, *Mactra solida?* *Saxicava rugosa*, *Corbula gibba*, *Mya truncata*, *Turritella terebra*, *Buccinum undatum*, *Murex erinaceus*, *Nassa sp.*, *Balanus tulipa-alba*.

Brown Boulder clay overlying preceding, but separated therefrom by a bed of gravel.

Ostrea edulis, *Mytilus modiolus*, *Leda pernula*, *Cardium edule*, *Astarte sulcata*, *var elliptica*, *Cyprina Islandica*, *Tapes virgineus*, *Tellina balthica*, *Mactra solida?* *Saxicava rugosa*, *Corbula gibba*, *Mya truncata?* *Turritella terebra*, *Buccinum undatum*.

I have made no microscopical examination of this drift.

BRAY.—North of the river Bray the following section is to be seen: it is a continuation of the same cliff of drift extending from Killiney, but offers some peculiar and highly interesting features.—(*Plate* 3).

* "Irish Naturalist," vol. iii., pp. 17, 18.

About half a mile north of the river Bray there is to be seen at the base of the cliffs, and on the shore, what may be designated as basement clay, underlying the gravels and gravelly till and loamy deposit. A decided line of demarcation exists between them. The hard basement clay can be seen on the plane of the shore, and boulders, often striated, can be seen *in situ* embedded in the clay. The collection of rocks exhibits a larger proportion of Cambrian quartzites and granites, and less limestone than the overlying drift, or any of that already described. The overlying drift is of the usual gravelly and loamy character. Flints can be found in the basement clay. I took out of this clay a perfect *Turritella*, and also a large fragment of a large *Cardium*, very strong, with quite a porcellanous glaze on the inside. It was embedded partly under a pebble, and the clay was so hard that I had some difficulty in digging the shell out with a knife. *Nassa reticulata*, *Astarte*, and *Tellina* occur in the overlying drift.

A notable feature in this basement clay is the axial direction of many of the embedded boulders. The longer axis generally has a N.W. direction, or between W. and N., but usually more north. The striæ on the boulders also point in this direction. There are stones with striæ in various directions, but these are more often the rounded stones. The tendency is N.W., but the stones lie not necessarily horizontally, but often obliquely to a horizontal plane.

Another feature in this clay is the existence of what may be called dykes of laminated clay. These obliquely or vertically lying bands can be traced from the cliffs on to the shore, where they present the laminæ on edge. There are also dykes of gravel nearly vertical. I have marked on the section the principal examples of the

features distinguishing this basement clay, which is brown and very hard.

A specimen of the basement clay was taken for mechanical analysis, and yielded the following results:—

Weight before washing = 6 ozs.

Caught in	1-20 inch mesh	.. ..	·166
„	1-40 „	.. ..	·041
„	1-100 „	.. ..	·072
Passed	1-100 „	.. ..	·260
Clay = ·461			·539

The 1-20 material consisted of green Cambrian grit and schist. Mica schist (Silurian ?), vein quartz, black chert, black and grey limestone, quartzite, crystalline quartz, a few exceedingly rounded minute pebbles of black limestone. 1-40.—A good deal of fragmentary quartz and vein-quartz, some extremely rounded and polished grains of quartz, mica schist, mica flakes. 1-100.—A crystal of quartz, many mica flakes, some rounded quartz grains; otherwise like 1-40. Passed 1-100.—Largely quartz and mica.

The gravelly and loamy drift above, is full of shell fragments.

At Ballycorus, about 2¾ miles from the coast and 3 miles N. W. of Bray, just north of the shot tower, we took out of a gravel pit a fragment of the interior of the umbone part of a cardium and other indeterminable fragments, at a level of about 230 feet above the sea.

Bog Hall Brickworks.—About 1 mile from Bray, on the road to Kilmacanoge, is the brick pit of the Bog Hall Brickworks. It is roughly about 200 feet above sea level. The clay is of a rusty brown colour, and I was struck by the absence of limestone. On examining the burned bricks also they seemed to be free from the

calcined pebbles, common in bricks made from Boulder Clay. This, considering the enormous amount of limestone drift spread over the country, was remarkable. A further examination, on a second occasion, showed that there were two clays, the lower apparently containing only Cambrian rocks and granites. These Cambrian rocks were often large and well-planed, and striated on a system, not furtively, like some of the limestone boulders of the marine drift. One piece of Cambrian measured 3 feet 6 inches long, and a block of Quartzite Conglomerate, 1 foot 8 inches long. There were many large granite boulders; one measured 3 feet in diameter.

The upper buff-coloured clay appeared to have a greater variety of rocks embedded in it. I got out a large flint which was so firmly embedded that it broke in getting it out. There are some large limestone boulders lying about which apparently came from the upper clay.

A specimen of the lower clay was taken, and microscopic examination confirmed the absence of limestone. None of the material retained in the sieves effervesced with acid.

The following is the mechanical analysis of 6 ozs. of the clay:—

Weight before washing = 6 ozs.

After—			
Caught in the	1-20 mesh	.. ..	·236
,,	1-40 ,,	.. ..	·059
,,	1-100 ,,	.. ..	·173
Passed	1-100 ,,	.. ..	·243
			·711

Clay = ·289.

The 1-20 material consisted of angular fragments of Cambrian rocks, schists, grains of quartzite, quartz

vein. A very fine granitic-looking rock weathering very rough on the surface. A few worn fragments—also non-calcareous.

1-40 mesh.—Quartz grains from disintegration of granite, schistose grains. Some extremely rounded and polished quartz grains, other grains like fine granite, flakes of mica. Non-calcareous.

1-100 mesh.—Similar to foregoing, angular fractured quartz grains, also some rounded and highly-polished quartz grains. A green deposit, like copper, occurred on a quartz grain. A considerable amount of mica.

Passed 1-100.—Grains like preceding, but not rounded. Does not effervesce with acid.

The remarkable feature is the absence of lime rocks and the unexpected presence of rounded, polished quartz grains, evidently marine sand, as there are no rocks that they could be derived from in the watershed. The angular and rounded quartz grains do not shade into each other so regularly as is common in shore sand.

Bray Head.—This fine headland is composed of much contorted purple and green slates and gritstones, with beds of quartz rock, supposed to be of Cambrian age, and containing *Oldhamia antiqua*. The drift clings to the precipitous sides of the headland as it does at Howth—particularly at the south side of the Head, where with some trouble we got a specimen at about 170 feet above sea-level, but did not observe any shell fragments. On the shore south of Bray Head, towards Greystones, are to be seen good sections of Boulder Clay, with abundant shell fragments. I also picked up in one place quite a number of red sandstone pebbles, exactly like the Triassic sandstone of Newtown Ards in County Down, 100 miles to the north. This probably came

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from there, as the only other known exposure is in County Monaghan, unlikely to yield it for this locality. The included stones consist largely of limestone and granite.

Glacial striæ are to be seen on the quartzite of the Head. On the side of the cliffs they point N.W., but the direction on the top is N. 20° W. In consequence of the quartzite breaking up into small blocks there is no large area of surface with continuous striæ. At about 650 feet above sea level we noticed a granite block 3ft. 6in. × 3ft. × 3ft. 3in. lying upon the quartzite.

THE GREAT SUGAR LOAF.—At Greystones (reached by rail), the rocks remind one of Bull Bay, Anglesea. The drift can be seen to extend southwards. Taking an outside car, we drove through the Glen of the Downs a gap in the range, of a similar character to the Scalp, but on a larger scale, and cut through the Cambrians of the Survey instead of the Granite. It is V shaped, and covered luxuriantly with trees. There appears to be very little of a stream except in heavy rains. From the north end of the Glen we ascended the Great Sugar Loaf. At about 800 feet above the sea is a gravel pit, consisting of angular fragments of Cambrian rocks, amongst which purple slate was prominent. There were pieces of granite lying about. At about 1,000 feet above the sea, a granite boulder occurred, and another at 1,100 feet measuring 2 feet in diameter. At this level the talus of the quartzite peak of the Sugar Loaf begins, and continues to the top of the cone. The summit is, according to the Ordnance Survey, 1,659 feet above O.D.; the ascent for the last 400 feet is very rugged from the fallen blocks of quartzite. Descending on the east side, the talus extends for nearly 1,000 feet down the mountain. At a

level of about 1,100 feet above the sea, we noticed small excavations, which disclosed the fact that the talus at that point rested upon a pure quartzose angular sand, more than 5 feet deep, how much more I don't know. At 880 feet above sea level a granite boulder was observed among the talus, and at 550 feet another, 3 feet in diameter and well rounded. Lower down in a little valley was a much larger granite boulder embedded in the bottom, the top part only shewing. At this point the quartzite is quarried.

Before leaving the Sugar Loaf it may be well to call attention to the remarkable effects of denudation in weathering out cones from quartzite. Here in Ireland the topographical effect is precisely similar to that of the quartzite cones described by Sir Archibald Geikie in his "Scenery of Scotland," and due doubtless to similar causes, namely, the very regular breaking up of the quartzite, and consequent equality of denudation on all sides.

Getting on to the main road to Bray, at a level of about 400 feet above the sea, on the east side of the road a gravel pit is seen, consisting largely of limestone boulders and gravel, which is got for burning. There are large granite blocks amongst it. On the west side of the road, at a level of about 380 feet above the sea, and bearing E. 10° N. of the Great Sugar Loaf, there is an Esker-like mound excavated for gravel, which in constitution and bedding is precisely like the Greenhills, Esker, to be presently described, and the fine gravel runs like shot. After careful search we found shell fragments, but mostly so decayed that they exfoliated and crumbled into a chalky mass in the hand.

There is a similar pit on the opposite side of the road, a little nearer to Bray. Fine gravel, capped with

Boulder Clay. The gravel runs like shot. The shells are very chalky, and crumble in the hand. Level about 320 feet above sea.

Amongst the shell fragments was a fragment of *Cardium*. Most of the shells were indeterminable and very carious, shewing the laminæ very plainly in some cases. The shell substance is quite perforated with cavernous holes, becoming in some cases a mere network of powdery calcite.

Another Esker-like mound, conical in form, occurs on the west side of the road, at about a level of 340 feet above O.D. (*See Section, Plate* 4). In this was a limestone pebble with a bit of shell cemented to it.

A *Turritella* occurred here nearly whole when got, but crumbling rapidly away; also, *Cardium edule* and *Modiolus?* the rest very carious, two-thirds eaten away and crumbling into powder, of which there is a good deal.

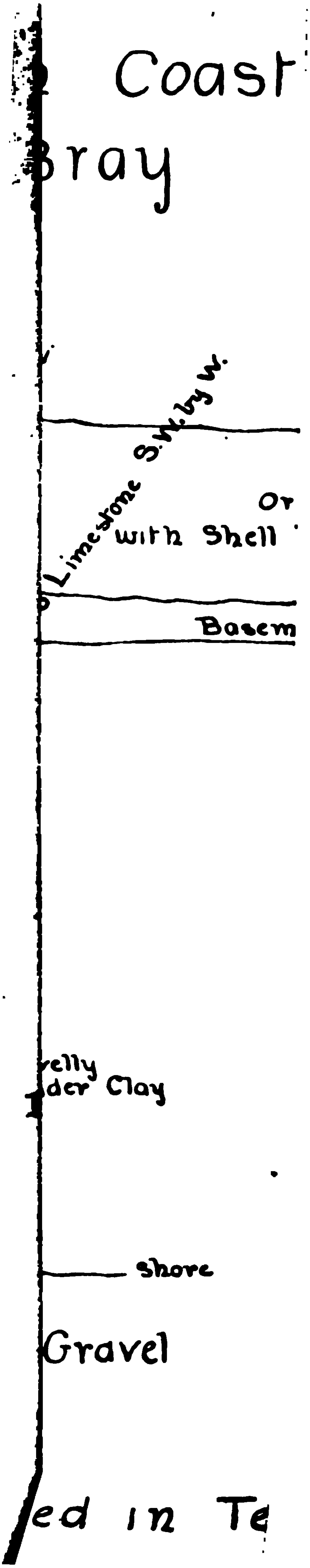
A specimen of this drift was submitted to mechanical analysis without washing, with the following result:—

Weight before riddling = 6 oz.

Caught in	1-20 mesh..	·715
„	1-40 „	·177
„	1-100 „	·072
Passed	1-100 „	·032
		·996

The material caught in the 1-20 mesh consisted of well-rounded limestone pebbles, mixed with others not much worn. The smaller grains of limestone are well worn. Three shell fragments.

1-40 mesh.—Shell fragments in a chalky state, mica flakes, small dark limestone grains. Quartz grains, some spherical and well rounded. Some black grains not affected by acid.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1-100 mesh.—Larger proportion of quartz grains and more of them well rounded and polished, granite grains and mica flakes. Calcite and, what I think are altered shell fragments.

The sand has a marine character, but not so distinctly as that of Howth. One crystal of quartz rounded and polished, but the crystal faces still distinguishable. The material that passed the 1-100 mesh was dirty and effervesced strongly with acid.

There is quite an amphitheatre of drift here, as if a torrent had cut out an escarpment, but at present there is no stream in the valley, only a flat bog. The vale seems filled with Esker-like stuff taking undulating forms.

Valley and High-Level Shelly-Drift.

I have now described the coastal drift, and some of the inland drift immediately connected with it. It now remains to trace the drift up the main valleys and connect it with the High-level shelly drift.

Glennasmole.—Under the guidance of Mr. Close and accompanied by Mr. Praeger, we spent one of the pleasantest of days exploring this valley. The weather was simply perfect. In the drive up by the river Dodder, vertical cliffs of limestone gravel and boulders are displayed on the banks. River terraces are also prominent features, giving splendid demonstration of the lowering of the river channel. There is a great deal of drift in the valley still, but much must have been removed.

At a level of about 570 feet above the sea I examined the drift on the bank of a tributary stream, and found it buff-coloured and clayey, mostly limestone, but

containing also granite, Ordovician grit and felstone, some of the limestone being striated. A gravel pit occurs on the east side of the valley, immediately above the reservoir of the Rathmines Water-works, at a level of about 860 feet above the sea. Very careful search yielded a few shell fragments of the ordinary type, but indeterminable; most were chalky and carious. Here as elsewhere, we met with fragments of recent land shells, but these are quite distinguishable from the type of fragments common to the shelly-gravels.

A mechanical analysis of this drift, taken about 860 feet above sea-level, yielded the following result:—

Weight before riddling = 6 ozs.

Caught in	1-20 inch mesh	.. ..	0·545
"	1-40 "	.. ..	0·194
"	1-100 "	.. ..	0·184
Passed	1-100 "	.. ..	0·077
			1·000

The material caught in the 1-100th inch mesh contained two microscopic bits of shell in a very spongy condition, having lost most of the shell structure. The grains of quartz are mostly angular and splintery, and I found no really rounded grains. There is much mica and granite débris.

In this fine material occurred a short siliceous cylindrical body. Dr. G. J. Hinde, to whom I submitted it, together with other microscopic cylinders, of which I shall have more to say bye and bye, pronounces them to be sponge spicules, mostly from the anchoring ropes of hexactinellid sponges, evidently the débris of carboniferous rocks, probably shaly limestone.

Glencullen.—This was another trip in which we had the advantage of Mr. Close's guidance, and local

and geological knowledge. A drive from Bray took us to the Scalp, a gap in the granite hills, which forms a sort of physico-geological crux, on which geologists are much divided in their theories.* On the south side the Silurian mica schist is seen lying against the granite.

The Gap is a V shaped valley, having a water-parting far in the gap to the north.

There is very little water in the stream.

Numerous blocks of granite encumber the ground, and if these be post-glacial certainly argue a great lapse of time. Formerly the Scalp was overgrown by trees, but fortunately a fire taking place, many were destroyed, for the benefit of geologists and lovers of the picturesque. After driving back to the southern end of the Scalp, we left the car, and walked to Glencullen. Here is to be seen a splendid expanse of section of a yellowish-buff coloured drift. I took a specimen of this drift at a level of about 390 feet above the sea, but it is of such a stony nature that it has to be got out with the chisel.† It is mostly full of Carboniferous limestone pebbles of a dark blue colour, some well worn and many well striated—some of the boulders intensely so. There is also a considerable proportion of granite, and many flakes of mica.

The granite is of two kinds, pink and grey, no doubt to the largest extent local. Boulders are to be found of a red conglomerate from the base of the Carboniferous, formerly looked upon as Old Red, the nearest locality *in situ* being, Mr. Close says, 14 miles away, but he

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* Mr. Kinahan has recently discussed the various explanations in the pages of the *Irish Naturalist* (Vol. II., page 241).

†A good photograph of the Glencullen Glacial Sands and Gravels, illustrates Professor Grenville Cole's paper, "County Dublin, Past and Present."—*Irish Naturalist*. I am much indebted to this paper for guidance in my rambles.

thinks it cannot all have come from this patch. The granite seems to increase in quantity as we ascend the glen, until at Glencullen Bridge little else is seen at the surface, the granite blocks being, in some cases, of considerable size. Mica schist was also found in the drift, and many cemented blocks of gravel were to be observed in the stream. Here also in Glencullen, as in Glennasmole, are evident signs of the removal of great quantities of drift.

Glencullen Bridge, by my aneroid, is about 600 feet above the sea, and the drift is continuous to at least 1,000 feet above the sea. Here, as in Glennasmole, we are struck with the great development and continuity of the drift to high levels. All this essentially limestone drift lies upon granite, and the bed rock is seen at Glencullen Bridge.

Before leaving this valley it will be well to mention that further south, below Enniskerry, stratified yellow sands, full of mica, with thin beds of limestone gravel, and a bed of crushed granite, are seen on the right bank, not far from the road. These appeared to be about 100 feet thick, and stand astonishingly vertical. Black bands of cemented limestone pebbles no doubt assist the sands to maintain this attitude.

In the cuttings for the abandoned Railway, now much overgrown, sections of a basal-drift of large boulders are to be seen, but there is nothing characteristic to record. The Carboniferous conglomerate also occurs here as boulders, and many granite blocks, some Ordovician mica schist, grits and felsites—some of the granite was well foliated.

The cutting is in the Ordovician shales, and many large blocks of granite rest on, or are embedded in them.

Ballyedmonduff.—A walk of about a mile and a half brought us to the famed gravel pit of Ballyedmonduff, some thousand feet above the sea. It was here that Mr. Maxwell Close was the first to note the occurrence of shells in the gravel, of which he gave an account in the "Geological Magazine,"* and so proved the extension of the High-level shelly gravels to the Sister Isle about on the same parallel of latitude as in Britain.

The gravel is mostly limestone, with a good proportion of granite boulders, also felstone, porphyry, Silurian grit, and purple conglomerate. Shell fragments are readily seen. The gravel is interbedded with sand, loamy sand, and sand and gravel. Some thin, contorted beds were to be seen (*See Section, Plate* 4).

A specimen from A was submitted to mechanical analysis, and yielded the following results :—

Weight before riddling = 5 ozs.

Caught in	1-20 inch mesh	.. ..	·625
"	1-40 "	.. ..	·225
"	1-100 "	.. ..	·125
Passed	1-100 "	.. ..	·025
			1·000

The material from the 1-20 mesh was well-worn gravel, mostly limestone, mixed with angular and subangular gravel—one piece of black limestone very polished and slightly striated, pebble of ochre.

1-40.—Something like preceding on a minuter scale, and more quartz grains.

1-100.—Many well-worn grains of quartz, rounded and polished limestone grains, calcite, mica flakes, very decayed grains of shell substance. Three sponge spicules were found in this material (*siliceous cylinders*).

The stuff that passed the 1-100 mesh was very dirty.

*Geo. Mag., 1874, "The elevated Shell-bearing Gravels, near Dublin."

SPECIMEN C.

Weight before washing = 6 ozs.

Caught in 1-20 inch mesh	.. ..	·791
„ 1-40 „	.. ..	·065
„ 1-100 „	.. ..	.052
Passed 1-100 „	.. ..	·031
		·939

Clay = ·061

There was a loss of 7 per cent. in washing which may be called clay.

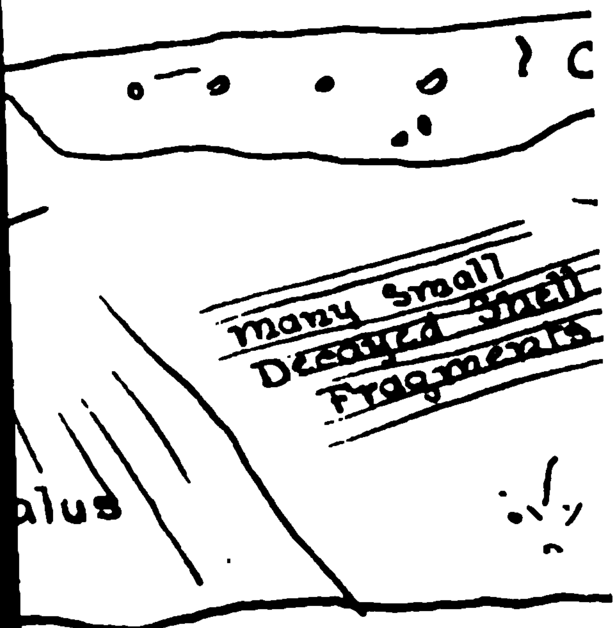
The material of the 1-20 mesh is limestone and granitic gravel. There was much more granitic matter than would be noticed in the field—many mica flakes, shell fragments, some felsite pebbles.

1-40.—This is largely quartz, and a good deal of calcite, some grains of shell, but not very characteristic. The general character of the quartz grains is angular, but I found a few rounded grains. Much mica.

1-100 mesh.—One extremely rounded and polished ellipsoidal grain of quartz occurred in this stuff. A few grains were rounded, but mostly angular. Much mica. There appears to be quartz, vein-quartz, limestone and calcite, and felstone in all the samples.

We unfortunately had no time to make a collection of shells. Mr. Close gives these species in his paper:—*Trophon muricatus. Fusus? Turritella communis. Ostrea edulis. Pecten* (two species). *Cardium edule. Cardium echinatum. Astarte compressa. A. elliptica. A. sulcata. Cyprina Islandica. Artemis lincta. Venus striatula. V. casina. Lutraria elliptica. Mactra stultorum? Tellina? Mya truncata? Pholas crispata. Balanus balanoides.*

Further on we find the remains of a gravel pit now grass-grown. When Mr. Close first saw it, it was in a



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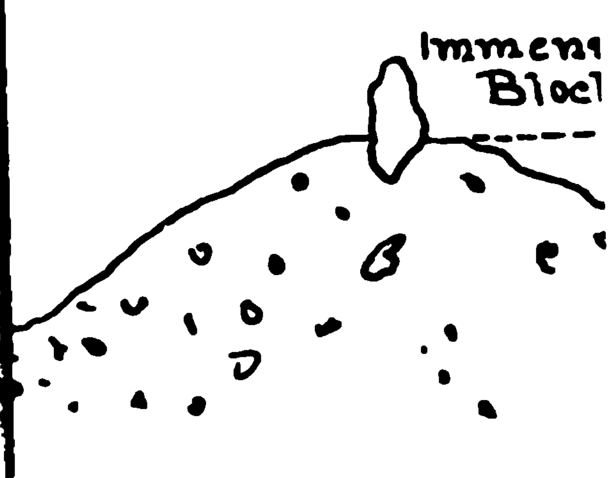


raine-Lough

SPECIMEN C.

Weight before washing = 6 ozs.

Caught in 1-20 inch mesh	.. ..	·791
" 1-40 "	.. ..	·065
" 1-100 "	.. ..	.052
Passed 1-100 "	.. ..	·031
		·939

Clay = ·061

There was a loss of 7 per cent. in washing which may be called clay.

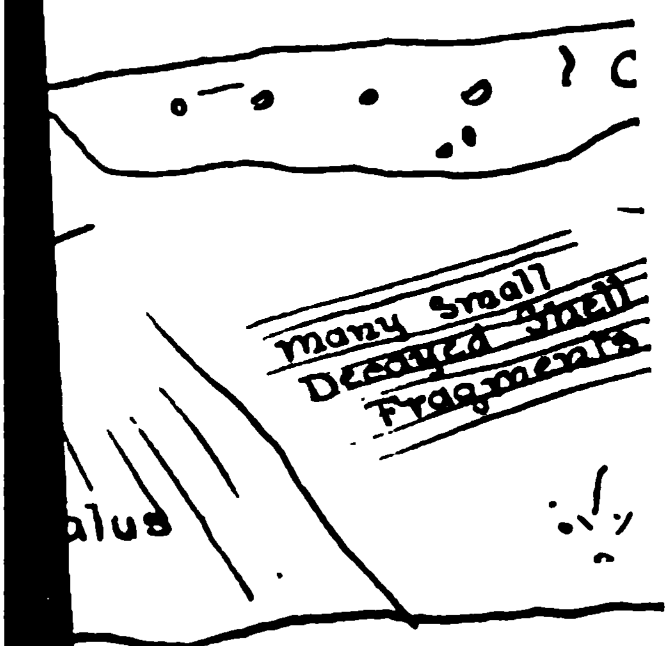
The material of the 1-20 mesh is limestone and granitic gravel. There was much more granitic matter than would be noticed in the field—many mica flakes, shell fragments, some felsite pebbles.

1-40.—This is largely quartz, and a good deal of calcite, some grains of shell, but not very characteristic. The general character of the quartz grains is angular, but I found a few rounded grains. Much mica.

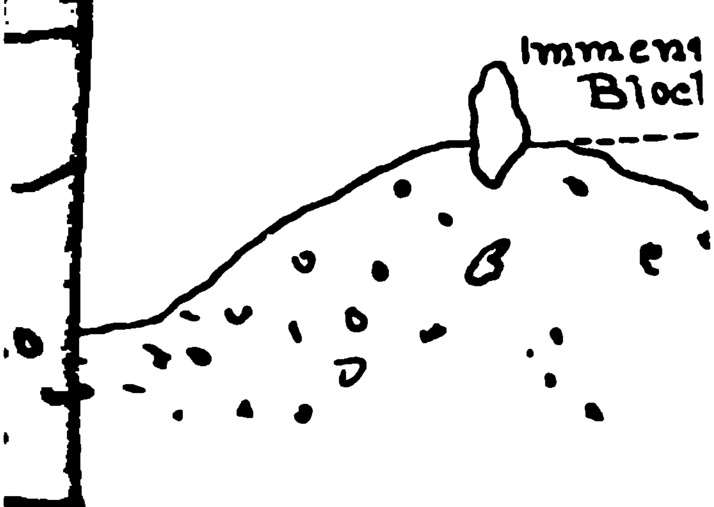
1-100 mesh.—One extremely rounded and polished ellipsoidal grain of quartz occurred in this stuff. A few grains were rounded, but mostly angular. Much mica. There appears to be quartz, vein-quartz, limestone and calcite, and felstone in all the samples.

We unfortunately had no time to make a collection of shells. Mr. Close gives these species in his paper:— *Trophon muricatus. Fusus? Turritella communis. Ostrea edulis. Pecten* (two species). *Cardium edule. Cardium echinatum. Astarte compressa. A. elliptica. A. sulcata. Cyprina Islandica. Artemis lincta. Venus striatula. V. casina. Lutraria elliptica. Mactra stultorum? Tellina? Mya truncata? Pholas crispata. Balanus balanoides.*

Further on we find the remains of a gravel pit now grass-grown. When Mr. Close first saw it, it was in a



und between (
f Great Sugar L
380 ft. above



raine-Lough

mound or mamelon, which afterwards was destroyed by the excavation of the gravel. The level is about 60 feet less than the previous gravels. We could see no shell-fragments, but Mr. Close records a good many species, in his paper, from this pit. Near the remains of a house called Caldbeck Castle, about 2 miles to the north-west, and 1200 feet above the sea, Mr. Close found further deposits of shell-bearing gravels. In the Killakee valley, between Tibradden Hill and Killakee, there is an immense, irregular accumulation of drift, and, at 850 feet above the sea, shell-fragments occurred, as also at the head of the valley, where the military road passes at a height of 1200 feet, fragments of *Cyprina Islandica* and *Astarte elliptica* were found. Also on Montpelier Hill, at an elevation of 1200 feet, one indeterminable shell fragment was found.

Lough Bray.—From Bray to Lough Bray is one of the regulation drives. Notwithstanding, the geologist will find much to interest him. At Curtlestown in Glencree, west of the Catholic Church, is a gravel pit, of which the gravel is mostly granitic detritus mixed with some limestone pebbles, and contains many large granite boulders, and some mica schist fragments. A more unlikely place for shells I never saw, yet I found one fragment of a bivalve after a few minutes' search. The level is about 770 feet above the sea. At a level of about 1100 feet, just behind the Christian Brothers' Reformatory, and above the military road, there is a gravel pit in the decayed granite, and at the top, granite boulders occur. This is not drift, but slow gravitational movements of the decayed material make it simulate bedding in places. No doubt it was this sort of decay that has yielded so much material to the drift.

There are two Lough Brays—Lower and Upper; they are corries in the granite mountain, with very precipitous scarps on the upper side, and great moraines at the lower. I made the lower lake to be 1,225 feet above the sea, and the upper 1,480 feet, the top of the moraine being 1,560 feet, or 80 feet above the water of the lake. Very large boulders rest on the ridge, one about 25 feet high. I exhibit a transverse section of the moraine—(*Plate* 4). It is certainly remarkable how such an immense bank can have been piled up from so limited an area, and the building of it must have taken a great length of time. It certainly gives strong evidence against the notion that the glacial period disappeared suddenly, as the ice must have lingered on this mountain, for the moraine could not be formed, excepting when the ice had an inextensive development.

There are great blocks of granite scattered about down Glencree.

The moraines are covered with heather, so that it is impossible to see if the stones are embedded in a matrix, or merely piled on one another. The granite decays very fast, and the detritus covers the surface. No doubt the humus acids of the peat, of which there is a good deal, help to destroy and round the blocks of granite.

Eskers.—The only Esker I was able to examine was the Greenhills Esker, about four miles out of Dublin. We commenced at the Balrothery end, about four miles S.E. of Dublin, close to the river Dodder. Mr. Close again acted as our guide. My son Aleyn found a small fragment of a *Turritella* in the gravel pit in the esker at Balrothery, and I found a small piece of shell very chalky and worn, which Mr. R. D. Darbishire recognised

as *Mya*. Also some extremely minute and indeterminable grains of shell. Mr. Close saw these taken out of the gravel, and was naturally surprised, as it has been a long established dictum that no shells or shell fragments have ever been found in eskers; yet here we found them in the first bit examined! No doubt they are very scarce, but bringing practised eyes to the work was a great help. Several pebbles of granite were found in this part, there are a few felstones and grits, otherwise the gravel is almost entirely limestone. The stuff looks very barren. It is bedded and current bedded, fine sandy gravel and shingle interlocking the usual way, and looks in places as if white-washed from the deposit of carbonate of lime on the gravel.

A specimen of the fine gravel was taken, and yielded to mechanical analysis the following results:—

Weight before riddling = 6 ozs.

Caught in 1-20 mesh..	·375
„ 1-40 „	·277
„ 1-100 „	·309
Passed 1-100 „	·034
	·995

In the 1-40 material two grains having shell structure were detected, also two other grains, probably the same. The material is mostly dark and grey limestone, and the grains pretty well rounded. A siliceous cylinder (sponge spicule) was found in the 1-100 material.

The Esker runs in a narrow sinuous line, first in a north-westerly direction, and then north-easterly, widening out at the termination, and developing a mound-like character at Drimnagh Castle; the total length is about 2½ miles. A main road follows the top of the Esker for most of the distance. At Tymon Castle we examined another small gravel pit in which we found

a pebble of very hard red porphyry, but could see no other rock of a granitic nature. Near the high road, beyond Greenhills, there is an immense gravel pit, in which is seen a development of gravel beds perfectly horizontal. In one a Till-like deposit occurred, and of this I took a specimen. The whole bank here appears to be a monotonous assortment of limestone gravel; I could find no granite, but flint and flint chips were frequent. The regularly stratified beds cross the pit in sweeping undulations, terminating against a sandy loam and gravel, in an abrupt manner. The whole of the ridge is below the 300 ft. contour. The southern end is given in the ordnance map as 290 ft., the northern at 254 ft. above O.D.

The specimen from the northern end yielded the following:—

Weight before washing = 6 ozs.

Caught in	1-20 inch mesh	.. .. ..	0·458
,,	1-40 ,,	.. .. ..	0·095
,,	1-100 ,,	.. .. ..	0·131
Passed	1-100 ,,	.. .. ..	0·135
			0·819

Clay = 0·181.

The material in the 1-20 inch mesh was nearly all limestone gravel, pretty well waterworn and smoothed, some chert, and apparently some flint. In the 1-100 material I found sponge spicules (siliceous cylinders), and also in the material that had passed through the 1-100 sieve.

The 1-100 material is largely quartz and calcite, and flakes of carbonate of lime.

Flakes of mica are found in all the smaller material, and granitic sand has been present.

RÉSUMÉ.

There are several characteristic and interesting features in the Shelly-Drift, described in detail in the preceding pages, namely, its extensive development, great thickness, and the facility with which it can be traced continuously up to the highest levels.

Contrary to what we find in Wales and the Lake District, it penetrates into and is found in great force in the interior valleys. The preponderance of limestone gravel on granite mountains is another striking feature. The limestone must have been swept from the north-west, and occurs in the esker-like mounds between the big and little Sugar Loaf, ten miles from the outcrop of the limestone resting on Cambrian rocks. The limestone gravel increases in quantity northwards, and is found on the Three Rock Mountains, many hundred feet above its origin. That the whole of the drift is marine, is to my mind indisputably proved by the presence of shells at every level, associated with extremely rounded and polished sand grains.

There must have been an enormous denudation of the Carboniferous limestone, and doubtless to the abundance of this material and the orographic features of the ground and mountains on which it has been unloaded, is due the great development of drift. The mountains have been unable to sustain glaciers during submergence, as in Wales and Cumberland, by which the inroads of the marine drift were barred out of the interior valleys in those districts.

At Bray, on the coast north of the river, and at the Bog Hall Brickworks, there are signs of an earlier Boulder Clay, composed more largely of the Cambrian and Granitic rocks brought down the valleys from the

south-west, and mixed with the northern drift. Rocky materials from Antrim and the north of Ireland are found mixed sparsely with the local materials.

Compared with Lancashire and Cheshire, the far-travelled rocks are in much less proportion, and so far as I was enabled to judge, there was an absence of such large far-travelled erratics as are found scattered over the country from the Lakes to the Midlands.

Finally, as bearing on the origin of the Shelly-Drift, I could see no evidence to support the Irish Sea Glacier hypothesis, for the travel of the drift materials, excepting as regards some of the sand, has been towards, and not from, the Irish Sea. The striae on the bed rocks tell the same story. It is also a remarkable fact, that the vertical limit of the Shelly-Drift is so similar in Ireland to that of England and Wales. The sporadic nature of the High-level Shelly-Drift has been dwelt upon with great insistence; but can it be called sporadic, when we find it at all levels, over such an extent of country as has been described in these pages, filling up valleys, hundreds of feet deep, and spreading a mantle over the flanks of mountains?

NOTES ON THE TRIASSIC ROCKS OF NEW JERSEY, U.S.A.

By W. Mawby.

(Read 13th March, 1894).

The system of rocks correlated with the European New Red Sandstone is scattered over the vast area of North America in what appear to be isolated basins. These isolated basins are separated by long ranges of

intervening country, and consist of sandstones, limestones, conglomerates, shales, and igneous rocks, the latter being of especial importance on the eastern seaboard. Unimportant though they may appear, judging from superficial extent alone, they yet yield in interest to none, recording as they do the history of the great and important changes which took place during their deposition. The American geologists term these strata collectively the "Jura-Trias," on account of the difficulty of deciphering any trustworthy line of demarcation between the two systems in the Western States—that is, between the Triassic and the Jurassic. The general aspect of the New Red Sandstone, on the eastern side of the American continent, is much like that of our own, both lithologically and palæontologically. The observations I present to you will chiefly apply to these rocks as exhibited in the vicinity of Jersey City, New Jersey. They occupy an area on this eastern seaboard roughly estimated at 10,000 square miles, and occur in detached masses throughout a length of 600 miles. The system here consists of sandstones, limestones, conglomerates, shales, and igneous rocks, the latter being especially noteworthy. The most important fossils are the fish, which occur in the black shales prevailing in certain districts, and which are generally characterised by the presence of fish remains, although these are often rendered indistinguishable through being baked by the igneous rocks either intruded through or extruded over them. All these fossil fish hitherto discovered are ganoids, and it is important to bear in mind, as tending to enlighten us upon the conditions obtaining at this far distant period, that most of the living ganoids inhabit fresh water. These fossil ganoids often occur in great numbers over a small area,

in a very good state of preservation, suggesting that they were very suddenly killed; possibly by the extrusion of the thick lava sheets, beneath which, in many instances, they lie. They seem to have been extremely limited in distribution, as the specimens from North Carolina, New Jersey, and the Connecticut Valley, are of different species. To turn next to the plants, the remains of which are very scanty. They are mostly specimens of equisetæ and conifers, much crushed and triturated. This is only what we may expect from the nature of the enclosing sediment. The more delicate portions have been, of course, destroyed, and only imperfectly preserved stems, twigs, and cones remain. They, however, serve to indicate the proximity of a land covered with vegetation, it may even be with forests, from which issued the numerous reptiles and possibly birds, indicated only by footprints occurring at different horizons. Although plant remains are extremely few in that portion of the Trias included in New Jersey and the Connecticut Valley, they are numerous further south in the coal-bearing shales of Virginia. Ferns and equiseta are here numerous, together with varieties of the pine family allied to the *Araucaria*. At the present day the genus *Araucaria* is confined to a narrow belt lying on the south side of the Equator, and is peculiarly southern in range of habitat. The Virginian shales possibly correspond to the Rhaetic beds of Europe. The almost total absence of molluscs, in the system of rocks under consideration, is very remarkable. Of course, there is also to be noted the absence of such purely marine organisms as corals, sponges, or echinoderms, but the want of these might be accounted for by assuming that the sediments were deposited in waters not having regular communication with the ocean. Possibly the mollusca were unable to

exist in this and other similar areas owing to the constant changes of elevation taking place at this period. Not the least interesting of fossil remains are the ichnites of various insects and crustaceans, which are especially numerous in the Connecticut Valley. In the black shales of Weehawken, near Jersey City, occurs a small crustacean Esteria ovata. It is by no means common, and I am indebted to Professor F. L. Nason, of the New Jersey Survey, for a specimen. He opines that the different species of Estheria are characteristic of different horizons.

There is a striking similarity between these rocks and the English Trias, in the frequent occurrence of beds showing ripple marks, sun cracks, and rain drop impressions, which occur throughout beds of great thickness, pointing to deposition in shallow water subject to regular tidal influences. Various theories have been advanced to account for the paucity of life throughout this system. It has been suggested, with regard in particular to that portion occupying a part of New Jersey and Connecticut, that violent tides prevailed such as at present exist in the Bay of Fundy, or that deposition was performed in partially land-locked lagoons, containing water of such extreme brackishness as to preclude the prevalence of even molluscan life. The area is intersected by enormous masses of diabase, which were ejected contemporaneously with the deposition of the sandstone. May it not be, that from the large fissures through which these masses were ejected, were also exhaled quantities of gas and soluble salts, effectually preventing or destroying all organic life. The strikingly tropical aspect of the fossils, seems to me to completely dispose of the supposition that anything approaching the nature of an "Ice Age" characterised Triassic times

on the North American continent. Glaciers, of course, may have prevailed in the higher parts of the Appalachian Range. If the Rocky Mountains had not been upheaved at this time, that superabundance of moisture necessary for the existence of glaciers, may well have been obtained from the winds sweeping across the continent, laden with aqueous vapour from the Pacific Ocean. It is important to note that no fossils are known from beds of this period which would suggest an arctic temperature.

The surface features of the geology of this region are interesting. Archaean rocks, rich in mineral ores, occupy the northern portion of the State of New Jersey. Here the country has a mountainous character over a total area of about 900 square miles. The surface is covered by glacial drift, which fills up many depressions, and forms thick beds on the lower levels. The outcrops of the rocks are rounded and polished, and afford excellent examples of ice action. Another noteworthy feature, due to ice agency, is the difference in the angles of the slopes in particular directions. Thus to the north-east the ground is fairly level, the slope is long and gentle, and there seems to be a greater body of alluvium than on the south-western slopes which, in contradistinction, are steep and rapid. In view of the discussion at present proceeding in several scientific periodicals, it may be useful to observe that in this mountainous region, immediately to the north of the great terminal moraine, lakes, lakelets, and ponds are numerous. Once having crossed to the south of the moraine, such sheets of water are almost entirely absent, and this change, combined with other topographical features, is very noteworthy. There is yet one other remarkable feature characterising the country to the north of the moraine,

and not shared by that to the south—it is, that in the north, the outcrops of gneiss and other rocks are excessively hard and comparatively unweathered, whereas, those to the south are remarkable for the amount of disintegration they have undergone. To such an extent has this proceeded that in some mines the rock can be dug out like clay at nearly 100 feet from the surface. The Triassic portion of the State of New Jersey lies between the Archaean rocks of the north-west and the cretaceous of the south-east, occupying an area of about 1,540 square miles. The great moraine stretches across this belt in a north-westerly direction from the mouth of the Raritan river.

Glacial drift prevails to the north, but the trap sheets, which stand above the general level of the country, afford the best indications of ice action in the rounding off of the angles of outstanding bosses, and in extremely fine striated surfaces. Erratics are very numerous.

The most widely known rock of this region is the ordinary brown sandstone. When microscopically examined it is found to consist of a great variety of mineral and rock fragments, but is in the main composed of grains of quartz and felspar, with flakes of mica interspersed, similar to our own Trias. At the base of the system occurs a conglomerate, a careful inspection of which better shows the diversity of material from which the sandstone was ultimately formed. This basal conglomerate is in some places over 100 feet thick. Next in importance to the sandstone are those volcanic masses locally known as trap; these occur as sheets and dykes of various sizes and extent. They are not confined to the sandstone strata, but extend into the surrounding territories throughout an area roughly estimated as 1,000

miles long by 200 miles broad. There can be little doubt that some of these volcanic masses were extruded contemporaneously with the surrounding sedimentary strata. In the immediate vicinity of Jersey City the trap generally occurs as a compact rock, being extensively used for building purposes. It also occurs in bands showing vesicular structure, and as an amygdaloid, with cavities containing secondary minerals. North of the great moraine the traps are centres of elevation, while south of this dividing line they form centres of depression. The explanation of this is found in the denuding agents; that in the north has been a mechanical one, acting with much greater power upon the comparatively soft sandstone than upon the hard trap. In the south, the chief force has been a chemical one, to which the trap is more susceptible than the sandstone, and hence the change in the trap has been most complete. As disintegration proceeds the mass crumbles into a red or brown clay, and it is often possible to scoop the material up with a trowel, like ordinary soil, at more than fifty feet from the surface.

THE PERMIAN CONGLOMERATE OF THE VALE OF EDEN.

By J. J. Fitzpatrick.

(Read 10th April, 1894).

The Permian period must always be regarded with deep interest by those who study the structure and composition of the stratified rocks. The climatic conditions prevailing, and the mode of occurrence and succession of the strata, tend to show that it was an eventful period in the earth's history.

Rocks of this age occur in various parts of England, from the extreme north, to the South Devonshire coast. The characteristic conglomerates and breccias of the period afford considerable scope for research and inquiry, to discover the causes which produced such remarkable accumulations of coarse material, and any investigation tending to show the conditions under which these rocks were deposited must be deemed of importance.

In a Paper read before this Society, on December 11th, 1888,* entitled "The Permian Conglomerate and other Palæozoic Rocks to the North of Morecambe Bay," I described an outlier of Permian Conglomerate near Humphrey Head, and in that paper I promised to continue my investigation by the examination of similar strata in the Vale of Eden and Shropshire.

I purpose, in the present paper, giving a short account of the Permian Conglomerate or Brockram in the neighbourhood of Kirkby Stephen and Appleby, in Westmoreland.

The local name Brockram is applied to these rocks in Westmoreland and Cumberland, and under certain circumstances, when the rock is of a coarse, brittle, and crumbly nature, to distinguish it from the more compact variety it is called "rotten" Brockram. The former is reddish in colour, and the latter yellowish-red.

The Brockram may be looked upon as the equivalent of the Rothliegende. The stratification, mode of occurrence, texture, and composition indicate that it is safe to correlate it with similar deposits in the Lower Permian of Germany. These rocks occur in the upper reaches of the River Eden,

* Proceedings of the Liverpool Geological Society, vol. vi., p. 42.

the most southerly exposure being at Thring Gill, a tributary of the Eden, near its source. They also occur in several localities in the Vale between Kirkby Stephen and Carlisle.

The rocks are well seen at Skenkreth, near the North-Eastern Railway Station, Kirkby Stephen, where the River Eden in its course to the north flows over the Brockram. Here the river has worn its channel through the rock, and in dry weather the bed of the river is seen showing a number of pot-holes in every stage of formation and decay. The river is spanned here by the North-Eastern Railway Bridge, and near it the main road through the valley also spans the river on a one-arched bridge. The river scenery at this part is wild and grand, and several beautiful waterfalls are seen in the rocky channel of the river.

A visit to the section at Skenkreth gives the observer an excellent opportunity of studying that which I consider to be the best exposure of the Brockram in the district. The rock is seen to advantage on the lines of dip and strike. It is hard, compact, and well adapted for building purposes, for which it is extensively used in the locality. The section under the bridge, upon which the main road crosses the river, is about 50 feet in height, and the fragments entering into the composition of the rock are well seen.

These fragments are almost wholly composed of Carboniferous Limestone, and vary from the smallest particle to about ten inches in length, and six or seven inches in breadth. The fragments are angular, subangular, and rounded; but at Skenkreth the angular fragments prevail, so that the rock may be described as a breccia or brecciated conglomerate, the fragments being cemented in a calcareous matrix. The matrix is

coloured with peroxide of iron, which gives the rock its distinctive reddish tinge. Besides the limestone there are small pieces of quartz, chert, and Silurian slate entering into the composition of the conglomerate.

In the limestone there are traces of Corals, Encrinites, and Brachiopods, but so much weathered that it is difficult to give the generic name with certainty. I was unable to find a fossil of any description in the limestone of the conglomerate at Humphrey Head, near Grange-over-Sands.

The stratification is well shown in the section at Skenkreth, and in the specimens which I am exhibiting the lines of bedding can be distinctly seen. On my first visit to this part of the river, which is locally known as "Cook Cony Hole," there was only a small quantity of water flowing, and the Brockram forming the river bed could be walked upon and examined without difficulty. At another visit the scene was completely altered, the river being swollen from heavy rains and quite impassable. The sound of the waterfalls, torrents, and cascades could be heard at a considerable distance.

At the North-Eastern Railway Bridge, where it spans the river, the dip of the strata varies from 5° to 7° to the north-east.

At the Brockram Field the rock is extensively quarried for building purposes. This field is near the Skenkreth waterfall, and the quarry may be reached by entering the field through a gate from the road leading to Kirkby Stephen from Skenkreth. The section exposed in this quarry is 130 yards in length, and varies from 12 to 20 feet in height. The stone is hard and durable, the matrix of a reddish colour, and the limestone in the conglomerate of a bluish tinge. The owner of the quarry is Mr. Joseph Snowden, Southa House, Kirkby

Stephen. On the main road to Nateby, between Skenkreth and Thring Gill, the Brockram crops out through the covering of macadam. This occurs more especially on the highest part of the road, and at the village of Nateby nearly all the cottages are built of the conglomerate.

In the Mallerstang Memoir of the Geological Survey, published in 1891, Mr. J. G. Goodchild refers thus to the rock as a building stone:—"In the neighbourhood of Kirkby Stephen the more compact and better bedded varieties of the Permian Breccias are rather extensively made use of, chiefly as a building stone; but though it forms, when well-selected, a good-looking and durable stone, the material is rarely sufficiently coherent to admit of its being dressed to any extent. Capital gate-posts are easily obtainable from these beds, and they seem to be in favour for this purpose at a considerable distance from the parent rock."

At Thring Gill, the most southerly point at which the rock occurs in the Vale of Eden, it rests unconformably upon the Carboniferous Limestone. Thring Gill farmhouse, a quaint old-fashioned building, is near the junction of the Carboniferous Limestone with the Brockram. The initials J. R., and the date 1715, are cut on a slab of Millstone Grit over the doorway. Thring Gill is a tributary of the Eden, and it was dried up on the occasion of my first visit. It flows by the end of the barn, and enters the Eden about 300 yards from the main road, which it crosses in a very primitive manner, the high road forming the bed of the stream, to the serious inconvenience of road traffic. The exposure at Thring Gill is merely the thinning out of the Vale of Eden Brockram, and rocks

of this description do not occur again south of this nearer than Humphrey Head, to the north of Morecambe Bay.

The area around Kirkby Stephen in which these beds can be traced, may be roughly described as measuring two miles from north to south, and about the same from east to west; the thickness being estimated by Mr. R. H. Tiddeman, F.G.S., at 200 feet. This area is overlaid by drift, which is largely composed of limestone fragments, probably derived from the immediate locality. A full account of the geology of the neighbourhood of Kirkby Stephen is given in the Geological Survey Memoir, published in 1891, entitled "Mallerstang, with parts of Wensleydale, Swaledale, and Arkendale (Explanation of quarter-sheet, 97 N.W., new series 40), by Messrs. J. R. Dakyns, R. H. Tiddeman, R. Russell, C. T. Clough, A. Strahan, J. G. Goodchild, C. E. de Rance, G. Barrow, and F. H. Hatch."

The name Mallerstang is given to the eastern flank of Wild Boar Fell, a rugged hill capped with Millstone Grit, the summit of which is 2,323 feet above sea-level. The River Eden flows almost due north at the base of this hill, which is six miles south of Kirkby Stephen. Mallerstang Common includes the slopes on the opposite side of the river. The poet Robert Southey, in "Brough Bells," refers thus to this locality:—

> "Up Mallerstang to Eden's springs,
> The Eastern wind upon its wings
> The mighty voice would bear;
> And Appleby would hear the sound,
> Methinks, when skies are fair."

Near this, on the opposite side of the vale, is Hell Gill Beck, a stream which flows from Black Fell Moss to the north-west of Black Fell, another lofty hill, 2,257 feet, and also capped with Millstone Grit. Hell Gill Beck is the source of the river Eden, and is situated

exactly on the boundary of Westmoreland and Yorkshire. Two miles south of Black Fell, near the summit of Abbotsloe, 2,186 feet, is Ure Head, the source of the river Ure, or Yore, which flows in a south-easterly direction towards the German Ocean.

The most southerly patch of the Brockram, at Thring Gill, is only five miles from Hell Gill Beck. This immediate locality forms an important part of the Pennine watershed, and contributes extensively to the river systems of the north of England.

The vale between Kirkby Stephen and Appleby is covered to a large extent with undulating hillocks and mounds of boulder drift, by which the solid geology is much obscured. This drift is mostly derived from the limestone of the district.

The following formations are met within a radius of ten miles of Kirkby Stephen :—

Trias	St. Bees Sandstone.
Permian ...	Penrith Sandstone and Brockram.
Carboniferous	Millstone Grit. Yoredale Rocks. Great Scar Limestone. Red Conglomerate Basement Beds.
Upper Silurian	Bannisdale Slates. ,, Flags and Grits. Browgill Beds.
Lower Silurian	Ashgill Shales. Black Limestone and Shale.

At Appleby, 10 miles north of Kirkby Stephen, there are some interesting sections of the conglomerate, and the rock assumes a rougher and coarser aspect. It can

be seen to the best advantage at Hungrigg Quarry, half a mile to the north-east of the North Eastern Railway Station, where sections in the lines of dip and strike may be seen. The dip is 14° to the N.E., and it is remarkable that at Kirkby Stephen and Appleby the rocks dip persistently in this direction. In this quarry the Brockram consists of large rounded and subangular fragments, chiefly of limestone; but sandstone fragments are also found in addition to the usual pebbles of quartz and chert. These are cemented in a calcareous matrix, although the fragments can readily be detached from the matrix, which is of a much lighter colour than that at Kirkby Stephen, being yellowish red, and both fragments and matrix are much weathered. The beds in this quarry are essentially the "rotten" Brockram, and the limestone fragments contain cavities which have been formed through the action of water, which has carried away the lime in solution.

This lime is afterwards re deposited as calcite in some of the cavities, and also helps to form the cementing substance of the matrix. The fragments are, in many instances, so much weathered that they crumble to pieces by the mere touch of the hand. Encrinites and Corals are plentiful in the limestone fragments. I have not seen, either at Kirkby Stephen or Appleby, any thin beds of sandstone intercalated with the strata of the conglomerate; but at Humphrey Head there are thin beds of fine sandstone interbedded with the Brockram.

At Brampton Fair Hill, on the old Roman Road, half a mile north of Appleby, there is an exposure of the coarse Brockram, and some of the beds here, unlike those at Hungrigg Quarry, are of a hard and durable nature. The dip is 18° to the N.E.

Mr. John Robinson, builder, Appleby, informed me that the soft Brockram from Hungrigg Quarry, when it is allowed to set, becomes hard and suitable for building purposes, and he kindly showed me a cottage which he had built with the soft stone from this quarry.

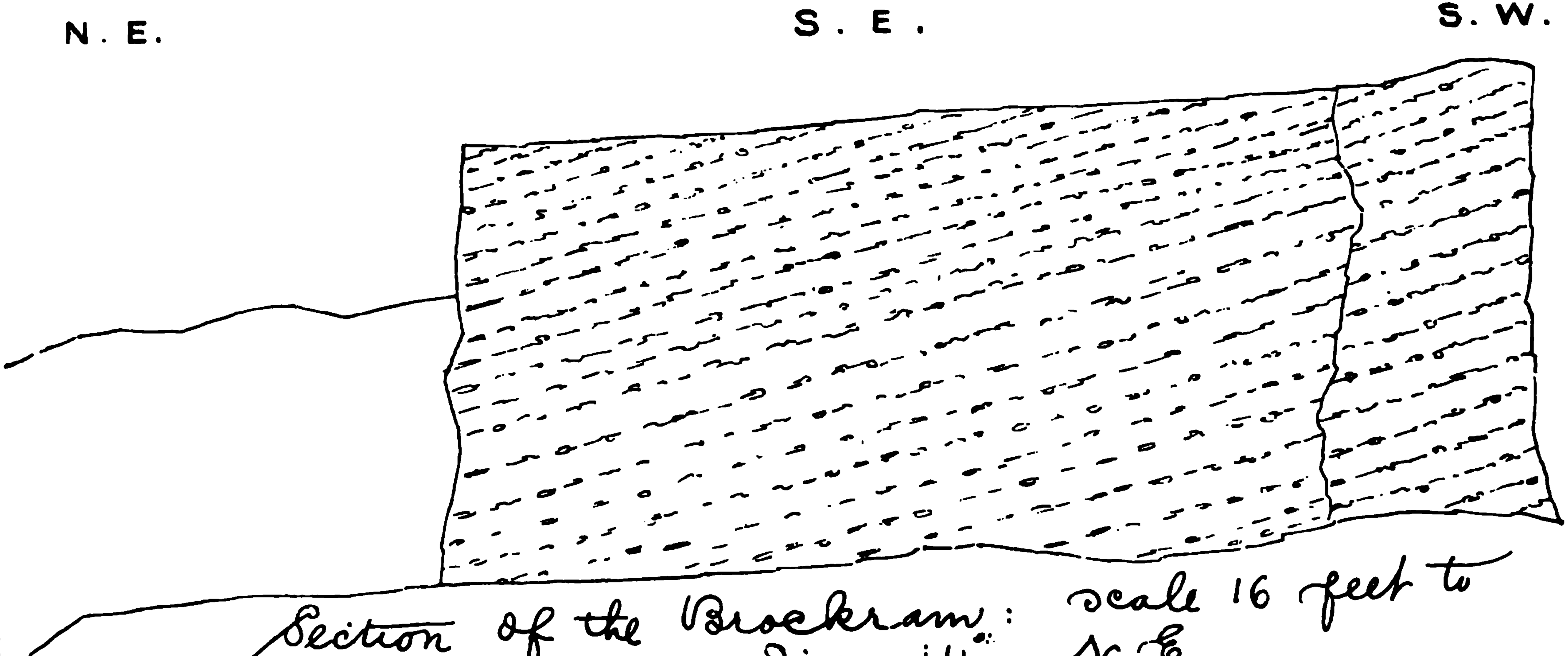
A small exposure of the rock occurs in a field on the farm belonging to the residence called the Friary, the entrance to which is on the Battlebarrow Road, going from Appleby in the direction of Penrith. This outcrop is about 300 yards north of the North-Eastern Railway Station, to the east of the line close to the embankment, and near the first railway bridge. It is the characteristic coarse brecciated conglomerate of the locality.

It is now desirable to compare the chemical constituents of the limestone, and the cementing material of the Brockram at Kirkby Stephen, Appleby, and Humphrey Head. I have to thank my friend, Mr. G. Watson Gray, F.I.C., for the following three analyses, one being of a characteristic fragment of the limestone from the Brockram Field Quarry, Skenkreth, Kirkby Stephen; the second is an analysis of the cementing material of the rock in the same quarry, and the third gives the constituents of a limestone fragment from the Brockram at Hungrigg Quarry, Appleby.

The following are the chemical constituents of a fragment of the limestone from the Brockram Field Quarry, Kirkby Stephen:—

Carbonate of lime	92·80
,, magnesia	2·27
Alumina	0·62
Peroxide of iron	0·48
Sulphate of lime	0·06
Insoluble siliceous matter	3·40
Loss, &c.	0·37
	100·00

HUNGRIGG QUARRY, APPLEBY.



Section of the Brockram: scale 16 feet to 1 inch. Dip 14° N.E.

J. J. F. 1893.

The cementing material consists of :—

Carbonate of lime	71·70
„ magnesia	1·97
Alumina	2·90
Peroxide of iron	0·80
Sulphate of lime	0·15
Insoluble siliceous matter	22·00
Loss, &c.	0·48
	100·00

A fragment of limestone from the Brockram, at Hungrigg Quarry, near Appleby, gives the following constituents :—

Carbonate of lime	39·60
„ magnesia	22·84
Alumina	4·76
Peroxide of iron	2·24
Sulphate of lime	0·17
Insoluble siliceous matter	29·80
Loss, &c.	0·59
	100·00

These results show remarkable differences in the chemical composition of the rock at Kirkby Stephen and at Appleby. The fragment from the Brockram Field Quarry, Kirkby Stephen, is almost a pure limestone, while that from Hungrigg Quarry, Appleby, is an impure description of dolomite, with 39·60 of carbonate of lime, and 22·84 of magnesia.

Another feature of interest is the large quantity of siliceous matter (29·80) which enters into its composition. The cementing material of the Kirkby Stephen Brockram has also a large amount of silica in its composition. The results differ very much from the analysis of the magnesian limestone, of which the rock at Humphrey Head is chiefly composed.

As a matter of comparison it is desirable to give the analysis of this dolomitic limestone at Humphrey Head. It consists of:—

Carbonate of lime	54·70
" magnesia	45·30
	100 00

The cementing material consists of:—

Carbonate of lime	37·80
" magnesia	28·40
Silica	10·00
Peroxide of iron	3·10
Alumina	16·20
Alkalies	2·50
Water	2·00
Phosphoric acid	traces.
Manganese	traces.
	100·00

It will thus be seen that at Kirkby Stephen the fragments are almost pure limestone, at Appleby an impure dolomite, and at Humphrey Head a pure dolomite, or magnesian limestone.

After diligent study and close observation of these rocks, it must be apparent to the investigator, that the deposition of these brecciated conglomerates must have taken place with comparative rapidity, and that those geologists who ascribe the lapse of great cycles of time for the deposition of the stratified rocks must exclude these beds from such calculations.

Professor Ramsay's theory, ascribing the origin of these deposits to the moraine matter of glaciers being carried on icebergs and deposited in the Permian seas, is familiar to all. In the fourth edition of his "Physical Geology and Geography of Great Britain," published in 1874, page 79, referring to the origin of these deposits, including the Brockram of Cumberland, South Stafford-

shire, Enville, Abberley, and Malvern Hills, he says:—"In my opinion these are simply old boulder clays."

In my previous paper I gave the following quotation from a communication upon the Permian Breccias near Whitehaven, read at the meeting of the British Association, at Belfast, in 1874, by Mr. R. Russell, C.E., F.G.S., of the Geological Survey, in which he advocates the ice-floe theory in a clear and distinct manner. He says, "Notwithstanding the angular and subangular character of the pebbles, there is much regularity in the stratification, and the distinct bedding shows that the materials must have been deposited in deep and still water, so that we cannot ascribe their formation to the transporting power of running water or tidal waves and currents, for the continued action of these causes would have destroyed the distinctive characteristics, viz., angular shape of the fragments, and the pebbles would have been rounded. Ice solves the problem. Periodical ice-floes cause regular bedding."

Mr. J. G. Goodchild, F.G.S., of the Geological Survey, who has done so much work in the Vale of Eden, has kindly sent me several of his geological papers, and amongst them there is the account of an "Excursion to Edenside," from the "Proceedings of the Geologists' Association," vol. xi., pp. xciv.—xcix., 1890, in which he says, in referring to Hungrigg Quarry, Appleby:—"The mode of arrangement of the constituents suggested that they had been deposited in an inland lake by floating ice. Just as this statement had been made Mr. William Atkinson discovered a large boulder from the Brockram, which showed unmistakable glacial striæ. This boulder, the first authentic example on record, was carried off by the party taking it in turn, and is to be deposited in the Penrith Museum."

The difficulty of finding glacial markings on the limestone fragments in the Brockram may be accounted for by the solvent action of water upon the limestone, as shown by the weathered condition of many of the fragments which contain cavities, from which the lime has been carried away in solution, to be redeposited as calcite and cementing material in the structure of the Brockram. This chemical action of water containing carbonic acid gas destroys all traces of striæ.

It is certainly of interest to note the absence of intercalated beds containing either flora or fauna in the sections which I examined. Then comes the question, have such organic remains existed, and have they been destroyed by chemical action?

I have already expressed an opinion* that periodical floods caused by the melting of snow on the mountains of Permian times, had much to do with the formation of these and similar deposits.

In South America, to the west of the Andes, and underlying the nitrate of soda deposits, there are superficial deposits, consisting of breccias, conglomerates, and sandstones, the stratification of which is of a similar nature to that of the Brockram; and in well sinking in the rainless district of Chili the coarse bedding can be seen in section. On the Pampa de Tamarugal, near Pisagua, these deposits occur over an area thirty miles in width, and about two hundred in length, and are the result of periodical floods caused by the melting of snow on the Andes. My friend, Mr. A. Watters, of the firm of Messrs. Watters Brothers, nitrate of soda merchants, Pisagua, to whom I have shown specimens of the Brockram, informs me that it resembles in structure and composition these superficial deposits on the

*Proceedings of the Liverpool Geological Society, vol. vi., p. 47.

pampas. Floods of this description, however, are not sufficient to account for the large areas in Russia and Germany over which these deposits occur.

In this paper I have only endeavoured to give a description of the Brockram in the upper reaches of the river Eden, and at a future time, with the sanction of the Society, I hope to contribute further notes which I trust may be of some value in seeking the solution of the problem of the origin of these deposits, the elucidation of which can only be obtained by diligent study of the physical aspect of the strata, the chemical constituents of which the pebbles and fragments are composed, and which differ so much, even in localities comparatively near each other.

I trust the additional notes which I have ventured to bring forward in connection with the structure and composition of these deposits may be of interest to the members, and, if so, it will encourage me to further efforts in the investigation of the history of the beds of this important period in the history of the stratified rocks.

EXCURSION TO BELFAST,

WHITSUNTIDE, 1893.

A party consisting of Messrs. Dickson, Hewitt, Ricketts, Goffey, and Mellard Reade proceeded to Belfast by boat, arriving there on the morning of the 20th May, and putting up at the Imperial Hotel.

After calling upon Mr. S. A. Stewart, at the Museum, the party took train to Newtown Ards, and examined the Scrabo Hill Quarry. The Rock is Keuper Sandstone, quarried for building purposes. Attention was called to the striking lithological similarity to the Keuper of the West of England. The quarrying operations have exposed good sections, showing that the sandstone is penetrated by dykes and sheets of basalt, a feature not present in the English Keuper. It was noticed that interesting structures were set up by contact action in the adjoining sandstone.

On return to Belfast, White Well Quarry, Cave Hill, was visited under the guidance of Mr. Stewart, and here the basalt was seen overlying the chalk, which it had converted practically into a limestone. The red colour of some of the flints was considered to be due to staining, and not "baking" as some suppose.

On the 21st the party was joined by Mr. Lloyd Praeger, who acted as leader for the day. Taking train to Killough, the shore of Killough Bay was traversed, attention being called to the raised beach 12 feet above high-water mark, upon which the Railway Goods Shed is built. Glacial polishing and striæ were noted on the edges of the Ordovician slate forming the country rock, which is exposed on the shore and lies in almost vertical beds. The striæ bear S. 20° E. and S. 10° E. A basalt boulder was noticed lying upon the slate. A Post-Tertiary beach, cemented together like concrete, was to be seen below high-water mark, big blocks of it lying about on the shore. A celebrated section of the Drift is to be seen in the shore cliffs. It consists of grey till at the base, ground from the slaty bed-rocks, and contains a large amount of striated Ordovician fragments, overlaid by a thick bed of brown sandy boulder clay, the total height of the cliff section being from 30 to 40 feet. The party walked on to Ardglass, and after dinner at the Hotel drove on to Strangford, where they crossed the Lough by boat, landing at a point south of Port-a-Ferry. The whole of this country is covered with mammilated hills of drift, reminding one of the forms and outlines seen in Wigtonshire. There is an immense mass of this drift spread over the low-lying country. Rounded pebbles of chalk

and flints are common in the drift near the coast, and have no doubt come from Antrim. On returning to Ardglass the party drove to Downpatrick, and returned by train to Belfast after a very enjoyable day. In the evening the hospitality of Mr. Joseph Wright was enjoyed, Mr. Gray and Mr. Stewart lending their aid to make a pleasant scientific re-union.

On the 22nd, still under the guidance of Mr. Lloyd Praeger, train was taken to Magheramorne, and the extensive deposits of Post Glacial Estuarine Clay examined. This clay has in part been forced up above high-water level to a maximum height of 15 feet, by the weight of the spoil from adjoining quarries tipped upon a section of it, is of the utmost interest. It is full of perfect post-glacial shells, in great variety*, pointing to a lengthened post-glacial period.

A visit to the Quarry, shewing a splendid section of the chalk and overlying sheet of basalt, completed the work at Magheramorne. Taking the train to Larne, a very careful examination of the Larne Gravels constituting a post-glacial raised beach, and full of Northern pebbles and boulders, well rounded, was made. The beach, it was pointed out by Mr. Praeger, rests upon the Estuarine Clay, which is full of foraminafera; also, there are worked flints throughout the gravels, but they are more frequent near the surface.† An examination of the interesting section of Glacial-marine drift at Ballyrudder was the last geological work of the party. This section was described in 1879 by Mr. Reade (Q.J.G.S., vol. xxxv. p. 679). It has since been very carefully investigated and described by the Belfast Naturalists' Field Club,‡ their report quite confirming the previous interpretation of this important drift section.

The party here divided, one section to go to the Giant's Causeway, the other to return to Liverpool. The thanks of the Society were voted to Mr. Praeger for his very valuable and kindly aid.

T. MELLARD READE.

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* See Report on the Estuarine Clays of the North-East of Ireland, by R. Lloyd Praeger, Proc. of R.I.A., 1892, pp 212-289.

† Report of Larne Gravels Committee. Proc. B.N.F.C., 1889-90.

‡ Report of Sub-Committee appointed to investigate the Gravels of Ballyrudder, County Antrim. Proc. B.N.F.C., 1892-3, pp. 518-525.

REPORT OF THE EXCURSION TO SHROPSHIRE, EASTER, 1894.

THE party met at Church Stretton on the evening of 22nd March, where they were joined by Dr. C. Callaway, F.G.S., who had very kindly consented to be their leader over the Cambrian and Pre-Cambrian Strata, and to explain on the ground his views as to the relation of these strata to each other.

On the 23rd, Dr. Callaway led the party up the Ashes Hollow, mentioning, in order that they might more readily understand what he was about to show them, that he considered the rocks from the Cambrian downwards, might be divided as follows :—

Cambrian, with *Olenellus* bed near the base	Fossiliferous.
Longmyndian	generally Stratified.
Uriconian	generally Volcanic.
Malvernian	generally Crystalline Schists.

The position of the Llandovery rocks lying on the side of the hollow, rather lower down than the point where the party had entered it, was pointed out as showing that a portion of the valley was excavated before or during Silurian times.

Proceeding up the hollow the various beds of the Longmynd, in an almost vertical position, were crossed, until a point was reached below a mass of Conglomerate, known as Narnell's Rock, where Dr. Callaway drew attention to an exposure of the junction of a bed of Shale with the Conglomerate, which, according to Professor Blake, is the unconformable junction between the Monian and basal Cambrian. Dr. Callaway, however, thoroughly disagrees with this view (see his Paper, "On the Unconformities between the Rock Systems underlying the Cambrian Quartzite in Shropshire."—Q.J.G.S., vol. xlvii., page 109).

After spending some time at this section, the top of the hill was crossed to an exposure of the Longmynd Conglomerate, which is traceable at intervals as far north as Haughmond Hill, where at an excursion of the Society, in 1876, Dr. Callaway pointed it out, showing a tolerably even strike for more than 20 miles.

As Mr. E. S. Cobbold, F.G.S., had mentioned the presence of erratics towards the northern end of the range, the return to Church Stretton was made past the head of Jonathan's Hollow to Plash Hill, above All Stretton, where a boulder of black basalt was found with

traces of a circular mound round it. Near it was noticed a small exposure of some gravel, and a boulder of Eskdale granite at about 1050 feet above O.D.

24th March.—Crossing the valley to the east side, Dr. Callaway led the party along the base of Caer Caradoc, near the line of the great fault. (See "Midland Naturalist," October, 1892, page 217, "The Silurian outlier west of Caer Caradoc," by E. S. Cobbold, F.G.S., &c.) A Quarry in the Upper Ludlow was examined, and from it some fossils were obtained. At the northern end of the range a small quarry (Comley Quarry) was visited, where the Cambrian Strata were seen lying against the side of the hill, and many fragments of *Olenellus Callavei* were obtained. The quarry and its contents are described by Dr. Callaway in a paper "On the Quartzites of Shropshire," in the Quarterly Journal of the Geological Society for 1878, pp. 758, 759; and by Prof. Lapworth, in his paper, "On *Olenellus callavei* and its Geological relationships."—(Geological Magazine, December, 1891).

Passing on to Shoots Rough, a small quarry in the Hoar Edge Grit (base of the Caradoc Sandstone Series) was examined, and on the roadside, after crossing a fault, an exposure of Shineton Shales. Returning to Comley Quarry, another quarry close by was visited, which in a more extended section showed the greenish Comley Sandstone with the *Paradoxides*-bed below, resting on the *Olenellus*-bed. Above the Quarry, on the side of Little Caradoc, attention was drawn to the outcrop of the Cambrian Quartzite (the lowest bed of the Cambrian), which appeared to lap round the hill like a sheet. Climbing Caer Caradoc masses of Dolerite were passed, and on entering the ancient earthwork on the summit, the Uriconian Rhyolite was seen distinctly bedded with an approximate E. and W. strike. Going on along the ridge Dr. Callaway pointed out a bed of fine mudstone, folded horizontally into a horse-shoe form; to this succeeded a volcanic grit. Rather lower down, on the lower side of the small wood, on the S.W. end of the hill, and about 100 yards distant from the exposure of grit, the Longmynd Rocks (Church Stretton Shales), with a N. and S. strike, were seen.

25th March.—The old road to Hazler turnpike was followed. The edges of the upturned shales of the Longmynd rocks were visible at intervals in the roadway, and at one point a granitoid rock appeared in irregular masses amongst slaty rocks. Microscopic examination had shown that it was really a quartz-felspar grit. Leaving the road by a bye-way on the right, leading along the ridge of Hazler, numerous exposures of volcanic Uriconian rocks were seen. On the other side of Hazler Hill, near Dryhill, a quarry was visited, to which attention had

been particularly directed by Mr. Cobbold. The quarry is in an amygdaloid, containing what look like fissures or veins filled with sandstone, with *Beyrichia complicata* and other Ordovician fossils, several specimens of which were obtained. These were first discovered by Professor Lapworth. Passing through Chelmick to Soudley, the well-known quarries were next visited and fossils collected. Keeping along the road towards Hope Bowdler the Harnage shales were seen, and on reaching Hope Bowdler Dr. Callaway pointed out in a farm-yard an exposure showing very clearly the conglomerate at the base of the Caradoc sandstone series, resting directly on the Uriconian. In the Woodgate Quarry the Uriconian grits were seen well exposed, with the usual E. and W. strike.

26th March.—Dr. Callaway having had to return home, the party drove to Wistanstow, from which point the well-known section along the river Onny was examined, and the day spent in following the succession of rocks, from the Wenlock Shale downwards, between Cheney Longville foot-bridge and Horderley, and noting the indications of dislocation, faulting, and disturbance that are seen near Horderley and between there and Marsh Brook.

27th March.—A visit was paid to Stokesay, and the members of the party present are indebted to the Rev. J. D. La Touche for the instructive and enjoyable day spent, under his leadership, amongst the Upper Ludlow and Aymestry rocks in the immediate neighbourhood. The thanks of all who took part in the Excursion must be given to Dr. Callaway, to whom in the main its success was due, and to Mr. E. S. Cobbold, F.G.S., of All Stretton, who, though unable to accompany them, assisted them very greatly with his intimate local knowledge.

HENRY C. BEASLEY.

Since the above was in type an excellent description of the geology of the district has appeared in the Proceedings of the Geologists' Association, vol. xiii., part 9, page 297, "The Geology of South Shropshire, by Prof. C. Lapworth, LL.D., F.R.S., and W. W. Watts, M.A., F.G.S."

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J C Branner
June 1. 95

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OF THE

Liverpool Geological Society.

SESSION THE THIRTY-SIXTH,

1894-95,

Edited by H. C. BEASLEY.

(The Authors, having revised their own Papers, are alone responsible for the facts and opinions expressed in them.)

PART 3. VOL. VII.

LIVERPOOL:
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1895.

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PROCEEDINGS

OF THE

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SESSION THIRTY-SIXTH.

OCTOBER 9TH, 1894.

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President—T. MELLARD READE, C.E., F.G.S.

Ex-President—E. DICKSON, F.G.S.

Vice-President—J. LOMAS, A.R.C.S.

Hon. Treasurer—THOS. GOFFEY.

Hon. Librarian—J. J. FITZPATRICK.

Hon. Secretary—H. C. BEASLEY.

Members of Council—E. M. HANCE, LL.B., W. HEWITT, B.Sc., H. ASHTON HILL, C.E., T. W. DAVIES, C.E., C. RICKETTS, M.D., F.G.S.

Mr. R. T. LITTON, M.A., 45, Queen Street, Melbourne, Australia: proposed by W. Hewitt and Thos. Goffey, was elected a Foreign Corresponding Member; and Miss LAURA J. SHIPTON, 35, Coltart Road, Prince's Park, proposed by A. R. Dwerryhouse and J. LOMAS, was elected an Associate.

The PRESIDENT then read the Annual Address:—

AIDS TO GEOLOGY BY CHEMISTRY.

NOVEMBER 13TH, 1894.

The PRESIDENT, T. MELLARD READE, Esq., C.E., F.G.S., in the Chair.

The following gentlemen were elected Ordinary Members of the Society:—

H. PERCY BOULNOIS, C.E., 7, Devonshire Road, Prince's Park, Liverpool: proposed by W. Hewitt, B.Sc. and T. Mellard Reade, C.E., F.G.S.

JOHN GOURLEY, 5, Derby Buildings, Edge Hill: proposed by H. Ashton Hill and H. C. Beasley.

EDWARD MARR, Aspen Grove, Lodge Lane: proposed by H. Ashton Hill and H. C. Beasley

H. B. NYE, 57, Kremlin Drive, West Derby: proposed by H. C. Beasley and J. J. Fitzpatrick.

The PRESIDENT exhibited on behalf of Mr. THOS. MOLYNEUX, C.E., a series of Fossil Fishes from the Oil Shales, of Broxburn, N.B.

The following Paper was then read:—

THE MORAINE OF LLYN CWM LLŴCH ON THE BEACONS OF BRECON.

By T. MELLARD READE, C.E., F.G.S.

DECEMBER 11TH, 1894.

The PRESIDENT, T. M. READE, C.E., F.G.S., in the Chair.

Mr. F. TATE, 9, Hackins Hey: proposed by W. Hewitt and H. C. Beasley, was elected an Ordinary Member.

EXHIBITS—

Fossils from Dryhill Quarry, Church Stretton. Dr. Ricketts.

Portion of Granite Boulder, from Chatsworth Street. The President.

Instead of a Paper, there was a Lantern Exhibition of slides of Geological interest, contributed by various members and friends, which were described by the Exhibitors.

JANUARY 8TH, 1895.

The VICE-PRESIDENT, J. LOMAS, Esq., in the Chair.

Mr. JOHN BRUCE, M.A., Ashford House, Birkenhead: proposed by W Mawby and J. Lomas, was elected an Ordinary Member.

EXHIBITS—

Plant Remains from Doulton's Delph, to illustrate Mr. Lomas's paper, by Messrs. Beasley, Bruce, Dwerryhouse, Lomas, Mawby, and Rock, and Miss Shipton.

The following Papers were read—

THE GEOLOGY OF THE COUNTRY BETWEEN PRESTON AND BLACKBURN.

By E. DICKSON, F.G.S.

NOTES ON SOME FOSSIL PLANTS FROM DOULTON'S DELPH, ST. HELENS.

By J. LOMAS, A.R.C.S.

FEBRUARY 12TH, 1895.

The VICE-PRESIDENT, J. LOMAS, Esq., A.R.C.S., in the Chair.

EXHIBITS:—

Mr. C. Potter exhibited some natural dendritic markings on a slab of stone, and a piece of earthenware with similar markings, artificially produced by a process which he described.

Mr. Lomas exhibited a stone anchor and several rock specimens from the Faröe Islands.

The following Paper was then read and illustrated with a series of views:—

THE GEOLOGY OF THE FARÖE ISLANDS.

By J. LOMAS, A.R.C.S.

MARCH 12TH, 1895.

The PRESIDENT, T. M. READE, Esq., C.E., F.G.S., in the Chair.

EXHIBITS:—

Specimens of the Cores from a boring being made at Ford, near Upton. By W. A. Richardson, C.E.

Specimens of Basalt and Basaltic Structure. Dr. Ricketts, F.G.S.

The following Papers were read:—

FURTHER NOTES ON THE SECTION AT SKILLAW CLOUGH, NEAR PARBOLD.

By E. DICKSON, F.G.S.

A THEORY TO ACCOUNT FOR THE HEXAGONAL FORM OF BASALT COLUMNS AND OTHER STRUCTURES.

By J. LOMAS, A.R.C.S.

APRIL 9TH, 1895.

The PRESIDENT, T. M. READE, Esq., C.E., F.G.S., in the Chair.

Miss RHODA DOUGLAS, 2, Moss Lane, Orrell Park, Aintree, proposed by J. J. FITZPATRICK and H. C. BEASLEY, was elected an Associate Member.

Mr. W. Mawby exhibited a slab of Sandstone, found by him at Storeton, bearing a double sinuous track, resembling that often left by a small crab.

The following Papers were read:—

FURTHER NOTE ON GLACIAL STRIATIONS AT LITTLE CROSBY.

By T. M. READE, C.E., F.G.S.

A DESCRIPTION OF THE STRATA EXPOSED DURING THE CONSTRUCTION OF THE SEACOMBE BRANCH OF THE WIRRAL RAILWAY.

By T. W. DAVIES, C.E., and T. M. READE, C.E., F.G.S.

FIELD-MEETINGS were held:—

1894.

April 28.—At Poulton Railway Cutting, with the Glacialists' Association, led by Mr. J. Lomas.

June 2.—At Dawpool, led by Mr. A. R. Dwerryhouse.

July 14.—At Burton Point Railway Cutting, led by the Hon. Secretary.

„ 18.—At Runcorn, led by Mr. A. Timmins.

1895.

Apl. 11/16.—At Appleby, led by Mr. J. Lomas.

LIVERPOOL GEOLOGICAL SOCIETY,

Dr. *In account with* THOS. GOFFEY, *Hon. Treasurer.* **Cr.**

	£	s.	d.
1894, Oct.			
To Postages, Mr. Hance		1	0
,, Geological Magazine to June, 1894	8	12	0
,, Palæontographical Society, 1892/1894.	3	3	0
,, C. Tinling & Co., Printing "Proceedings" and Circulars	40	2	0
,, Ed. Doling, for Session	5	15	0
,, Rent of Room, 1893	5	0	0
,, Minute Book, Stationery, &c.	1	1	6
,, Hon. Secretary's Expenses, 1892/3	3	3	11
,, Hon. Treasurer's ditto		2	6
,, Balance	2	17	3
	£64	18	2

	£	s.	d.
1893, Oct.			
By Balance from last Session		18	1
1894.			
By Subscriptions for Session 1893/4	31	10	0
,, Arrears	23	6	6
,, Donations	5	15	6
,, Subscriptions, a/c Palæontographical Society		15	0
,, Subscriptions, Printing Fund		10	6
,, Sale of "Proceedings"	1	15	11
,, Returned Carriage, per Mr. Doling		6	8
	£64	18	2
By Balance	£2	17	3

Audited and found correct,

(Signed), W. H. ROCK.
W. HEWITT.

E. & O.E.

(Signed), THOS. GOFFEY,
HON. TREASURER.

9th October, 1894.

PRESIDENT'S ADDRESS.

CHEMISTRY AS AN AID TO GEOLOGY.

(*Read 9th October, 1894*).

In selecting the subject of Chemistry as an aid to Geology I have been wishful to choose one appropriate for treating in a Presidential Address, and one which has not already been selected by my predecessors in this chair.

The "Proceedings" of the Society contain several papers, chiefly from the pen of the late Mr. Norman Tate, in which the aid of Chemistry is invoked to explain phenomena met with in geological research; but the majority of these papers are more or less a record of chemical facts, and it would have been outside the authors' scope to have dealt with these facts in regard to their general relationship to geological science. Allow me to make three exceptions to this statement and refer you to two papers by Mr. Tate, one on "The Relation of Chemistry to Geology," and the other on "The Chemistry of the Primeval Earth," both reported in vol. i. of the Society's "Proceedings." The other paper I would except is the paper by our President-Elect, Mr. Mellard Reade, "On the Solvent Action of Rain Water and its Influence as an Agent of Denudation;" the facts recorded and the conclusions deduced in which last-named paper now form part of the common stock of geological knowledge and literature. Since 1868, the date of Mr. Tate's paper, both Chemistry and Geology have largely extended their borders, so that the inter-relation—or shall I say inter-

dependence—of these two sciences is now much closer than it was twenty-six years ago. Each succeeding year finds every science—and, indeed, every branch of every science—tending towards extreme specialization; it is therefore an advantage to the follower in one line of enquiry to cross the boundary of his own science into some other, to examine methods there pursued, that he may see how far the results obtained in other departments bear on problems presented to him in his own particular branch of science.

It is no disadvantage that the respective methods of the sciences should differ. Prof. Judd has said: "The greater the divergence between the methods followed in two departments of science, the greater becomes the necessity for intercourse between the cultivators of them, and the more hopeful the results which are to be anticipated as being likely to follow from mutual suggestions and healthy discussion." (Chem. Soc. Journ., vol. 57, p. 404.) There is, and there must be, in modern science, a thorough inter-dependence of its many different departments. To the modern investigator it becomes, then, a necessity to gather what knowledge he may in other departments of research. It might at first sight appear that Chemistry and Geology had not much in common, as their methods are so essentially different. Chemistry is *par excellence* the science of experiment, whereas in Geology the experimental method can be applied to a limited extent only, and then only under definite restrictions. The latter science has to depend for its advancement upon other and very different methods of investigation. Geology, though comparatively a very modern science, has already passed through various stages. Commencing first as a branch of Mineralogy, it was by the work of the earlier geologists—Smith, Lyell,

Murchison, Sedgwick, De la Beche, and others—elevated to the rank of a separate science. The methods of enquiry pursued by these last-named geologists differed, however, from those of their predecessors, in that they based their investigations on observations mainly in the field, building up theories and drawing conclusions from causes which they saw in operation around them, paying perhaps too little regard to opinions considered by them at the time as too hypothetical. This might be termed the observational stage of the science. In the next stage of its history we find the chemist's aid invoked to analyse the various rocks and minerals that compose the earth's crust, and to describe the chemical effect of the action of water and other solvents, in order to explain the phenomena of weathering and decomposition of rocks, and to explain the genesis of certain deposits and rocks which the geologist was unable to account for by his usual methods of enquiry. This might be termed the analytical stage. Within quite recent years Geology has entered on yet another stage—the synthetical and experimental, and it is in connection with this later development that Geology has received so much assistance from Chemistry.

It has been said with truth that "few geologists are chemists and that fewer chemists are geologists," a remark especially applicable to our own countrymen. Although I shall in the course of this address name many who by their researches have advanced Chemical Geology, I cannot, with the exception of the late Professor Forbes, Dr. Sorby, Dr. Irving, and possibly one or two more, call to mind any English chemists or geologists who within the last fifty years have largely assisted in the attack of geological questions from a chemical standpoint. The subject has, indeed, attracted some attention in America, but to German, and more

especially to French, chemists are we most indebted for extensions of our borders in this field of research. Later in my address I will give in detail some of the discoveries made by Daubrée, Fouqué and Lévy, and other workers, which show how the minerals we find in the rocks of our planet, and certain of the rocks themselves may have been formed, and throw light upon the probable history of the magma in which the minerals occur and the changes which this magma may have undergone. For the present, however, I would call your attention to some of the ways in which Chemistry is likely to elucidate problems presented to us in the deposits and formations of our immediate neighbourhood. I may instance the origin of the Boulder Clay and the drift, a subject to which allusion has been made in papers * I have read to this Society in conjunction with my friend Mr. Holland.

Is Chemistry able to throw any light on the origin, mode of formation, and history of the drift-deposits, which present so many difficulties still unsolved? I believe it can. In the papers to which I have alluded, we distinguished between a mud and a clay, clay being defined as "hydrated silicate of aluminium," a body of definite chemical composition. In the paper read in 1889 (vol. vi. of the "Proceedings") we gave analyses and a description of the fine material usually known as glacial mud, issuing from beneath glaciers and which gives to glacial streams their characteristic milky appearance. It was pointed out that this so-called mud consisted solely of fine-ground sand, of which the very finest particles, when examined under the microscope, proved not to be clay but grains mostly of quartz, many of them stained with iron oxide. Furthermore, the analyses

* Proc. L'pool Geol. Soc., vol. vii., p. 108; vol. vi., p. 322.

showed that the actual clay suspended in the streams, and—in the case of the River Rhone—deposited at the head of the Lake of Geneva, was practically *nil.*

Of all Alpine streams this finely-ground suspended matter is a conspicuous feature, and has received the appropriate name of "rock-flour." It originates from the grinding of the stones against one another in the glacier itself, and by the grinding of the ice-embedded stones on the rock bed over which the glacier travels. I should wish here and in this connection to mention the important work undertaken in America by Mr. Crosby and others, and in England by our President-Elect, in mechanically analysing the drift deposits, as I consider that the results may prove of the highest importance in assisting to solve the question of their mode of origin. Mr. Crosby, in a valuable paper communicated by him to the Boston Society of Natural History, and printed in vol. xxv. of its "Proceedings," gives details of his examination of the till and drift deposits in that neighbourhood. By his mechanical analyses he found that the Boston till was composed of 40 per cent. of "rock flour," 12 per cent. of clay, 20 per cent. of gravel and 20 per cent. of sand; but that of the 12 per cent. of clay a very small proportion only proved to be *true* clay in the chemical sense, the greater part, indeed, consisting of extremely fine "rock flour." This "rock flour," which formed so large a constituent and so distinctive a feature of the till, proved to be rounded grains of quartz with adherent iron oxide, with here and there a few grains of felspar, showing that it was only the hardest and least easily decomposable minerals that had withstood reduction to clay. I regard these observations as of considerable inferential value, and would suggest that the

drifts and clays in our own neighbourhood should be examined, to ascertain in what respect their features correspond with deposits known to be products of ice action alone, without the intervention of other agencies —as, for example, marine action. A question which has often presented itself to me is, can these glacial deposits be differentiated from other deposits similar to them in appearance, but of non-glacial origin. Do the drifts generally, but more especially the clays, owe their present form and composition directly to the mechanical action of ice, and indirectly to that of subsequent decomposition and oxidation? Are the drifts made up of pre-glacially decomposed rock, and has the ice acted as a transporting or directive, rather than as a creative agent? Mechanical and chemical analyses of the clay would, I think, assist us here, the mechanical distinguishing the finer rock flour from the true clay; chemical analysis helping to throw light upon the source of the deposit, by showing whether such deposit be a derivative of the rocks on which it rests—as I am inclined to think is the case in this district—or whether it has been brought from a distance, and how far it has been affected by subsequent weathering.

Crosby is of opinion that the ice-borne deposits he describes have been so affected by subsequent weathering, and I think we may assume a similar action to have taken place on the glacial drifts in these islands, whereby matter, which at the period of its transportation by ice consisted mainly of rock flour, has, during the interval which has elapsed since the close of the Glacial Period, been converted into clay. It is quite possible that chemical action, as Crosby suggests, may have been in abeyance in glacial times. A low temperature retards chemical action, and *passim* the recent experiments of

Prof. Dewar show that extremely low temperatures will prevent it altogether in the case of some elements whose chemical affinities at ordinary temperatures are very marked. Crosby, in the paper referred to, gives a datum by which he distinguishes glacial from *non*-glacial clays. This datum is the combined water. He regards a 100 parts of true clay as containing 12 parts of combined water, and makes use of this number as a co-efficient in calculating the per-centage of true clay in the various deposits dealt with in his paper. The combined water in a glacial silt that he examined did not exceed 5·60 per cent., thus showing the deposit to consist of 46·6 per cent. of true clay, along with 53·4 per cent. of rock flour. In a clay that could be regarded as of probably *non*-glacial origin the combined water amounted to 10·4 per cent., which, translated into true clay, gives 86·4 per cent., the remainder, 13·4, consisting of rock flour. This was a clay from the Miocene beds of Martha's Vineyard.

I remarked just now on the probability of some of the clays of our own district being of local origin. As an example, I think we are justified in so regarding a clay lying on sandstone at Brereton Hill, near Rugeley. Analyses of this clay and the sandstone are given in a paper by Mr. Holland and myself, read to this Society in its last Session. A close correspondence between the figures for the clay and the sandstone is not to be expected, since in the conversion of rock minerals into clay the matter composing the minerals will no doubt be removed by water in the order of its solubility. Thus the rough clay will not consist of the uniformly altered rock on which it rests, but will contain *débris* of the parent rock in various stages of decomposition. The effect of removal of rock components by weathering will obviously

be to raise the relative proportion, though not in equal degree, of the elements composing the original rock which are least soluble and make up the residue. It would be a great gain to the Glacial Geologist, if he could find criteria that would enable him to assign to a clay its probable birthplace. By way of illustration I will assume that extensive beds of clay exist some ten miles south of Alderley in Cheshire, the origin of which has been matter for speculation. Calling in the aid of the chemist, he tells us he finds in conjunction in the clay the elements, copper, cobalt, and vanadium, elements known to occur in the rocks at Alderley Edge. This fact would strengthen any hypothesis formed on purely geological evidence in favour of assigning the origin of a per-centage of the clay to the Alderley rocks.

With regard to Crosby's plan for distinguishing glacial from *non*-glacial clays, it is of the first importance that the estimation of the combined water be made on the true clay, and not on the rough clay from which the gravel and sand have not been previously separated, since gravel and sand are almost devoid of combined water, and would for this reason, if not removed, falsify the estimation of the true clay. I think it would be of service to determine the amount of the true clay of the drift deposits in this neighbourhood. We might perhaps thus learn if the drift be a product of decomposition *in situ*, also learn something as regards the period at which the decomposition took place: for when rock masses are chemically decomposed *in situ* and the product is subsequently washed into valleys by streams, this material will contain less gravel and sand than will a "till" due to direct ice action which has been transported to the valleys by sub-glacial torrents. I may remark here,

that in all chemical analyses of rocks the combined water should always be collected and weighed, and not estimated by "loss on ignition." The water can then be tested in various ways, whereby useful information is often gained. It is too often overlooked that clays may be formed in many different ways. In the "Challenger" expedition it was found that enormous areas in the Southern Ocean were covered by red clay; but, though this deposit was not altogether unlike our Boulder Clay, it would be, I think, a bold hypothesis to assign to both a similar origin.

Before quitting the subject of clays, I will just record an observation with which some of you may not be acquainted. It is a noteworthy one, and may bear on "Sedimentation." It has been observed* that clay when suspended in water settles more quickly in salt than in fresh water, more quickly in liquids of high than in those of low specific gravity.† The rate of deposition of a silt may thus depend on the place of deposit, whether it be in fresh water or in salt; and the knowledge of this fact might help to determine whether a particular deposit took place in a fresh water lake or in the sea.

Clay, from its remaining longer suspended in fresh water than in salt, would, where the volume of fresh water is considerable, as in rivers like the Amazon or Mississippi, be carried further seawards than would be the case in rivers whose volume of fresh water is small.

The "Proceedings" of this Society contain many papers on the Red Sandstone rocks of our district, in

* Th. Schlœsing, "Determination de l' argile dans la terre arable," Comptes Rendus, 1874, remarked that clay suspended in water settles sooner if the water be rendered *very* slightly acid, or if certain salts be added.

†Durhaus, Chem. News, vol. xxx., No. 767. Robertson, Trans. Geol. Soc. Glasgow, vol. iv., p. 3. Ramsay, Q.J.G.S., xxxii., 129.

which almost every feature has been described in more or less detail; but I think that in only three papers has attention been called to their chemical aspects, the earliest in date being a paper by Mr. Tate (vol. i., 1862-3) on "The Composition of Black Sandstone in the Trias near Liverpool."

Another valuable communication, also by Mr. Tate, appears in vol. v., p. 284, "On Iron as a Colouring Matter of Rocks." In vol iv., p. 63, Dr. Campbell Brown gives analyses of the Red Sandstone from the deep bore-hole at Bootle (Sandstones belonging to the Pebble Beds and Lower Bunter). Should other analyses of the marls and sandstones of this district not yet have been made, I trust the omission is one that members of this Society will in time rectify. The sandstone rocks and marls of this neighbourhood (both Permian and Triassic) present several points of interest, to which I think little attention has been paid. A study of them on the lines I have indicated will, I venture to suggest, tell us something of the conditions under which these rocks were deposited. In my last Presidential Address I dealt briefly with the history of sand-grains, mainly from the chemical stand-point; and, as you well know, the physical character of the grains in our local sandstone has been thoroughly well considered by Mr. Morton, vol. v., p. 52, and by Mr. Reade, vol. vi., p. 374, of the Transactions of our Society.

Some sandstones are much richer in felspathic matter than others, those sandstones which owe their origin only indirectly to the granitic or schistose rocks containing less felspathic matter than do those which are the more immediate product of these last-named rocks.

It is useful at times to estimate the potash in sandstones, for when this is done it is only necessary to multiply the per-centage number of the potash by the

factor 5·911 to obtain that of the orthoclase. In many of the Triassic sandstones grains of felspar are common, but are often much decomposed. The cementing material is usually siliceous, argillaceous, felspathic, or consists of oxides of iron, which all these rocks contain, either in the ferrous or the ferric state. Dr. Clowes* has remarked the occurrence of barium sulphate as a cementing material in a sandstone near Nottingham. The observation is interesting from the fact of the high insolubility of this mineral in water (viz., 1 in 429,700 of water at 18·4° C. Holleman, Zeit. Physikal Chem. xii., 125-139).

Bischof also mentions (vol. i., p. 432) Continental conglomerates containing barium sulphate.

Dr. Clowes found the sandstone at Stapleford, Brancote Hills, and the Hemlock Stone to contain as much as 30 per cent. of crystalline barium sulphate, this mineral occurring in some of the beds in streaks, patches, and in more or less spherical masses.† (J. Chem. Soc., 1886; Chem. News, v. lii., 194.)

I do not propose to occupy your time with remarks on the colouring matters of sandstones, or the mottled appearance of the marls, with which all of us are familiar. It may be sufficient to say that Mr. Tate has treated the subject at some length in the paper to which I have already alluded. Mr. Maw, too, has done so, in an exhaustive and masterly paper (Q.J.G.S., 1868). The colouring of rocks, which was at one time assumed to depend entirely on iron in various stages of oxidation, is not now supposed to be due to the iron oxide *per se*, but to depend also on the presence of certain vegetal

*Irving, Brit. Assoc. Rep., 1883-4.

† Since the above was written, I am informed that Mr. Lomas has found barium sulphate in the Triassic Sandstones of Cheshire, at Caldy Hill and Bidston.

acids in conjunction with the precipitated iron oxide. Julien presented to the American Association of Science in 1879 an important paper on the part played by humic acids in this connection, that is to say in the colouring of the green marls of the Upper Keuper. Dr. Irving has devoted much attention to this same subject. His paper on "Organic Matter as a Geological Agent" (vol. xii., Geological Association Proceedings), is one of the fullest modern accounts of the action of these acids. He holds (Brit. Association Reports, 1885) that the induration of the sandstones and grits is due to these vegetal acids acting on the felspathic minerals, whereby they are split up, supplying the cement which binds together the grains of sand. Vegetal acids he considers to be the main agents by which the ferric and manganous oxides are dissolved from rocks, which oxides have at a later stage become precipitated, giving rise to the deposits of limonite as seen in the lakes of Canada and Sweden. The familiar rainbow colouring frequently observed on the surface of shallow pools containing decomposing vegetation is a film of ferric oxide, the ferrous oxide acquiring the additional oxygen from the air. The part played by vegetal acids appears to be an important one. In arable soil they are largely instrumental as carriers of those mineral salts which all crops and the many forms of plant life require. What I have just said as regards the part played by vegetal acids in dissolving cementing material, and in subsequently colouring and indurating sandstone, would infer the existence of life, either during or immediately prior to the Triassic period.

Now another of the many problems connected with these Red Sandstone rocks is the general absence of life in them; and the question arises, did life exist at the *time of their* deposition, and, if so, what may be pre-

sumed to have caused in so large a proportion of these rocks, the entire disappearance therefrom of every vestige of organised forms?* Prestwich gives four reasons for the rarity of fossils in the Red Sandstone rocks. (Geol. vol. ii., p. 166). Without going into this question as I would wish to do—indeed, it is one that can only be touched upon in a general address—I would ask, may not chemical action at the time of and immediately after the deposition of these beds have been instrumental in removing calcareous structures? It would seem that salts of iron when brought in contact with lime carbonate will react on the latter. The action would take place in the case of shells. My friend Dr. Chaster informs me that in the Birkdale sandhills, in the bed of an old slack containing vegetal *débris* highly charged with iron, he found great numbers of land and fresh water shells belonging to species still common. The shells were much eroded and very rotten, and he is inclined to attribute the rotten condition of the shells to the conjoint action of the iron and the humic acids, which were undoubtedly present in the locality in which the specimens were collected.

The observations of biologists on the occurrence and subsequent disappearance of life in the seas in the present time should aid geologists, for where ocean currents are swift, there molluscous life is sparse. In Triassic and Permian periods we find evidence of strong aqueous currents in the false bedding of the rocks. Thus the comparative absence of fossils in Permian rocks may be connected more with the conditions of the water currents inimical to life prevailing in Permian times, than with chemical conditions tending to the extinction of the fossils by solution.

*Proceed. Geol. Assoc., vol. iv., No. 3, 176.

I am inclined to the opinion that the rarity of fossils in Permian and Triassic rocks is due to a combination of causes, physical, chemical, biological, all tending to produce the same result; that owing to these causes acting, either in combination or separately, life was not abundant during these periods; and further that, in a large proportion of instances, all traces of life have since been removed, owing to the operation of chemical solution. The researches of Varigny and Bert (J. Chem. Soc., 1884, ii., 620), seem to me to throw some light upon the physical conditions prevailing during these periods. They found that if salt water were added to fresh, or fresh water to salt, animals of a lower type could live under the new conditions for a much longer period than those more highly organised, and that in time fresh forms appeared, differing in their smaller size from the original forms, but fitted for the altered conditions. Much of the life found in the Permian rocks is life that would be able to resist incursions of fresh water into salt and salt water into fresh, and the fact that the life generally appears to be dwarfed may be accounted for by the rise of generations better fitted for the altered circumstances than were their progenitors, as Varigny and Bert observed in their experiments.

In the remaining part of my address I will deal principally with the various means by which Chemistry may assist the geologist in settling the nature of the mineral components of rocks, and with the explanations afforded by Chemistry of the manner in which the minerals in the volcanic rocks are formed.

It is now some thirty years since Dr. Sorby first showed how the microscope applied to thin sections of rocks enabled the geologist to make out their structure.

It is needless for me to impress on your notice how much the science of petrology has been enriched thereby. Knowledge has been gained of the life-history of a rock to an extent that older geologists would have regarded as unattainable. Microscopical examination alone, however, is apt at times to lead the observer astray, and should be supplemented, whenever it is practicable to do so, by chemical tests or a full chemical analysis. Let us consider one or two ways in which a chemical analysis is useful to the petrologist.

1. It tells us of what acids and bases the rock under examination is composed, the nature and relative amounts of the elements present, and thus helps us to confirm or abandon an opinion based solely upon a microscopical examination. Thus an observer might mistake nepheline for apatite; but, as phosphoric acid is a constituent of apatite, resort to a few chemical tests will at once distinguish the two minerals.

2. Analysis will show, in cases of conterminous rocks, if there has been a transference of mineral matter from the one to the other, a point of interest in metalliferous impregnations.

3. Analyses of a series of rocks may serve to show the change a member of the series has undergone by the addition or removal of some particular rock-forming constituent.

4. Again, analytical data enable us in a general way to compare different individual specimens of rocks of similar character, and assist us to trace and explain alterations due to atmospheric or other causes, by an examination of altered and unaltered specimens of the same rock.

In order to identify and separate out the minerals that make up a rock, advantage is taken of the difference

in their relative specific gravities. By the use of fluids of very high, but of carefully ascertained density, minerals can be separated from one another. Some will float on the surface of the fluid, whilst others will sink, and some again, occupy an intermediate position. Aided in this manner, the observer may with a pipette effect a sorting-out of the different minerals. I may mention two liquids as generally serviceable—boro-tungstate of cadmium with a density 3·28, and bin-iodide of methylene, density 3·34. It is obvious that suitable dilution will give fluids of intermediate and known density, which will serve to further fractionate the earlier separations.

Sonstadt and Church were pioneers in this field of research, and employed Thoulet's solution of iodide of mercury in iodide of potassium. The sp. gr. is 3·19. Bréon in 1880 proposed a mixture of chloride of zinc and chloride of lead, but this mixture has the disadvantage of requiring to be used at a temperature of 400° C. Rosenbusch advocates the conjoint use of chemical and microscopical methods for distinguishing rock-forming minerals, and describes how in a thin section of a rock the minerals in the section may be locally treated with acid or other agent whilst on the stage of the microscope. This is done by the aid of a perforated glass cover coated with Canada balsam, the perforation in the cover being adjusted immediately over the mineral whose nature is to be determined. The action can then be observed with the microscope. As an example, bubbles of gas, on addition of dilute acid, would indicate the presence of calcite or other carbonate. With a capillary pipette the solution can be afterwards removed from the slide and tested for some known constituent of the supposed mineral so treated. In this way may a trace of apatite

be identified in a rock when to a droplet of the solution is added ammonium molybdate, which in the case of apatite would give the characteristic yellow crystal of phospho-molybdic acid. Native iron in a section of rock may be detected on treating a portion of the rock with a solution of copper sulphate. The mineral, if iron, would then present the red appearance due to the deposited copper on its surface. The late Professor Andrews, of Belfast, did in this way detect native iron in certain Irish basalts from Antrim, by immersing the basalt in a solution of copper salt. The system of micro-chemical analysis I am now describing has been still further extended by Professor Bořicky, of Prag, who treats minute selected fragments of minerals with hydro-fluosilicic acid, and takes note of the crystallographic forms of the fluosilicates so produced. To make this clear, it must be remembered that hydro-fluosilicic acid has a solvent action on rock-forming minerals, the bases of the minerals passing into solution as fluosilicates.

H. Behrens,* following in Bořicky's footsteps, replaces fluo-silicic by fluoric acid, dissolving the mineral in a small platinum crucible. After evaporation to dryness he re-dissolves the residue in dilute sulphuric acid and fractionates the solution, setting apart the fractions for special testing. This plan of working can advantageously be employed in conjunction with a previous separation of the rock minerals by means of the dense solutions just referred to.

I may mention here the assistance the spectroscope renders in the identification of substances present in rocks in very minute quantity, particularly when, as in the researches of Crookes, M. Lecoq de Boisbaudran,

* Zeit: Annal. Chemie, 1891.

and other chemists, the ignition temperature of the element is raised by the induction spark. I need but just allude to Crookes' able researches on the rare oxides found in certain Scandinavian minerals, as evidence of the value of optical methods of research in connection with the rocks of our planet.

Possibly Chemistry has rendered the greatest assistance to Geology in unlocking some of the hidden processes of Nature, by means of results obtained by certain French chemists, who have aimed at the production of rocks and rock minerals by synthetic methods. On reviewing the results arrived at by the researches of Daubrée, Moissan, Le Chatelier, Fouqué and Lévy and others, it may with truth be said that "Geology has become an experimental science;" but to what a small extent, since we cannot experimentally reproduce all the conditions under which some rocks have been formed. Thus we cannot artificially reproduce and maintain for a lengthened period the enormous pressure to which matter at the earth's centre must be subjected—a pressure estimated by Mr. Fisher to be not less than 3,000 atmospheres; nor, of course, can we experimentally supply the time which many of Nature's operations must have required for their consummation. It is not, then, a matter of surprise that the chemical geologist, though successful in some cases, should have failed to reproduce many rocks synthetically. Attempts to reproduce rocks of the acid type have been only too frequently attended with failure. The origin of granite and of the plutonic rocks generally is a riddle still to be solved, but that it *will* be solved I personally entertain little doubt, and regard the experiments of the French chemists, to which I will refer later, as likely to elucidate the origin of these rocks.

Before giving you in detail the methods adopted as the artificial reproduction of minerals and volcanic rocks, it will be interesting to notice the diverse means employed by the different experimenters. Sir James Hall it was who, in 1790, by his experiments on fused basalt, laid the foundations of experimental Chemical Geology.* He observed that the melted rock if quickly cooled became glassy and amorphous, but that if slowly cooled it became crystalline, and that to regenerate the crystals in the rock it was necessary to maintain the temperature of the melted basalt for some time at some degrees lower than had originally been required to fuse it. Thus slow cooling would appear to favour the segregation of crystals. Hall was followed by Watt, who showed that slow cooling of fused basalt did regenerate crystalline forms.†

Every geologist recognises with gratitude the debt he owes to Gustav Bischof. Bischof's work, "Chemical and Physical Geology," is a veritable storehouse, wherein is garnered the fruit of much careful thought and patient research; but Bischof, whilst wishful to avoid what he considered to be the heresies of the Huttonian school, undervalued the effects of thermal action, placing too much dependence on wet processes.‡ A preconception that Daubrée had to combat was the idea that the reproduction of minerals artificially was only possible under conditions unattainable in the laboratory; and further, the opinion that the laws which regulate mineral association in Nature differ from those which govern the combinations of the chemist.

* Trans. Roy. Soc. Edinb., vol. v. (1805); vol. vi. (1812).

† Phil. Trans., 1804. 279.

‡ President's Address, Q.J.G.S., vol. xxii. Rudler, "Experimental Geology." Proceed. Geol. Assoc., vol. xi., p. 86.

Now, it is interesting to compare the modes adopted by different workers for the artificial production of minerals and rocks. Daubrée, whose classical researches in this branch of experimental science are so well known,* made use of hydro-thermal reactions. By sealing up substances with water in glass tubes and exposing them to high temperatures, and consequently to considerable pressure, he was successful in obtaining Sanidine, topaz, diopside, apatite, and many other minerals. Le Chatelier † is of opinion that the purity and regular growth observable in the felspar crystal point to its formation in a fluid matrix, and that this mineral is not a result of extraneous matter acting at a later period of the history of the rock in which the felspar occurs. Among those who have successfully reproduced minerals by artificial means are Sarrasin, Friedel, Hautefeuille, Moissan, and others. In 1891 Chrustchoff succeeded in producing hornblende by heating the oxides of the constituent elements of this mineral to a temperature of 1,000° C. for three months. Frémy, recognising the importance of high temperatures, was successful in producing rubies by fusing the constituents of these gems at 2,700° C. for 100 hours. Indeed, his experiments were so far productive as to furnish sufficient stones for an ornamental collar. Moissan ‡ has also made small rubies by fusing alumina in a lime crucible, placed in an electric furnace which gave a temperature estimated at over 4,000° C. The discovery of the diamond in meteoric iron led Moissan § to consider the conditions under which the former had been produced in Nature, and to devise means

* Etudes Synthetiques de Geologie Experimentale (Daubrée).

† Comptes Rendus cxiii 370–373.

‡ Comptes Rendus, Dec., 1892.

§ Comptes Rendus, cxvi., 218–224.

by which the necessary conditions could be best imitated in the laboratory. How to dissolve pure amorphous carbon in molten iron and cause it to crystallize under pressure was the question; for, assuming this to be practicable on the experimental scale, the dissolved carbon might, as the iron slowly cooled, crystallise out as the translucent variety, and not as graphite. Molten iron, like water, increases in volume at the moment of solidification. Now if, in the act of solidifying, the expansion of the cooling metal be restrained by a sufficiently rigid envelope, it is obvious that the interior mass of iron must become solid under enormous external pressure. Moissan, when conducting his experiment, took a small iron tube closed at one end, which he filled with pure carbon, finally closing the mouth with an iron plug. The tube was next dropped into a crucible of molten iron, so that the iron in the crucible was thoroughly saturated with carbon. The crucible on removal from the furnace was plunged at once into cold water, so as to cool the molten iron externally. By this means a confining shell of metal was formed, within which the still fluid iron was allowed to solidify slowly at the temperature of the air. On dissolving the mass of iron when cold in acid, there remained a residue of graphite and minute crystals, of which some turned out to be diamonds, capable of scratching a ruby, and had the crystalline form of the natural gem. Moissan states that similar minute crystals occur in the diamond-bearing earth of the Cape.

I may just mention in passing some interesting analyses of diamondiferous rock and earth from Kimberley Mine, contributed to the "Chemical News" by Sir H. Roscoe,* who in the course of his work

* "Chemical News," vol. 50, 243-244.

observed that the "blue earth," when treated with boiling water, emitted a peculiar odour resembling camphor. On extracting a considerable amount of the earth with ether, an aromatic body was obtained which burned with a smoky flame. "The presence of this carbonaceous substance in the blue earth, tends to confirm Prof. Cohen and Mr. Dunn's hypothesis that the carboniferous shales which are penetrated by the diamond bearing 'pipes' have been the source of the carbon which is now found as diamond."—(Abstracts, "Journal of the Chemical Society," 1885.)

The fruitful experiments of Fouqué and Lévy, having for their object the synthetic formation of rocks and minerals,* differ from those of Daubrée in that they had recourse to igneous fusion of dry material. These investigators were successful in producing augite, leucite, certain felspars, garnet, and nepheline, as well as rocks of the augite-andesite and basalt class. They obtained these results by fusing together the silicates and oxides of which these rocks and minerals are composed, maintaining the fusion for some time at temperatures intermediate with the highest employed. By this means opportunity was afforded to mineral forms to crystallise from the fluid magma in the order of their fusibility. By subjecting the material of the fusion to successive re-heatings, the course assumed to be that of Nature would, it was thought, be imitated. Microscopical examination had shown that in volcanic rocks the various mineral substances were formed at successive and more or less regular periods, moreover, that there was unmistakable evidence of undeveloped or arrested growth of the crystals. A chief cause of the arrested growth is either a too rapid consolidation of the

* Synthèse des Minéraux et des Roches, Paris, 1882.

magma, or some fluxion disturbance; thus where we meet with perfect crystals, these we may assume, in the majority of cases, to have been generated in a tranquil medium, and under pressure, after the manner of Moissan's laboratory experiment for the crystallisation of carbon from fluid iron. The magma of a lava we may fitly regard as the mother liquid whence the material of the constituent minerals has been derived. With the above facts before him, the geologist can better determine, as it were, the life history of a lava, and speak with more certainty of the conditions under which the several crystals have appeared in it. Perfect crystals would appear in a vitreous magma in subterranean reservoirs, whilst microlites and crystallites originate during the outflow of the lava, as the fluidal arrangements so frequently met with show.

I will just give in detail the method by which Fouqué and Lévy synthetically obtained a basalt containing olivine, augite, and labradorite.* The particular rock to be reproduced was, in the first place, analysed so as to learn its general composition. From the information so gained a mixture was made up of three parts of powdered olivine, two of augite, and three of labradorite, and the whole fused to a black glass. The crucible and contents, after heating to a white heat for forty-eight hours, was allowed to cool. On examining the vitreous mass distinct olivine crystals were apparent. The fusion product was next returned to the crucible, which this time was kept at a cherry-red heat only, and the temperature maintained at this for forty-eight hours. The result of this second re-heating was a glass containing microlites of labradorite and augite, along with magnetite. In

* Renard on Artificial Reproductions of Volcanic Rocks, "Nature," vol. xxxix. (1888).

experiments of this kind a variation of the temperature and period of heating will often give rise to more than one variety of mineral. All Fouqué and Lévy's experiments go to show that modern volcanic rocks can be produced by a purely igneous fusion without the aid of water, whilst at the same time their failures show that other conditions must have prevailed when the rocks they unsuccessfully attempted to produce were naturally formed. Up to the present time all acidic rocks, and those containing quartz, mica, orthoclase, and hornblende, have withstood all efforts to reproduce them by synthetic methods.

Before leaving this branch of my subject, I will shortly notice an experiment made by Dr. Sorby some fourteen years ago,* which shows how different is the structure of natural granite from the same rock artificially fused and then allowed to cool. Dr. Sorby fused a ton of syenite from Crooby, near Leicester, and allowed it to cool slowly. On breaking up the mass it was found to contain long flat prisms of triclinic felspar, but no solid crystals of felspar, hornblende, or quartz. The structure, moreover, of such crystals as did appear in the artificially fused rock was essentially different from that of the crystals in the natural rock. Some thirty years ago Messrs. Chance, of Birmingham, endeavoured to utilise fused volcanic rock by running it into moulds. Specimens of Messrs. Chance's product were some few years since submitted to Professor Bonney, who found, as Sorby did, that the substance after re-fusion presented a structure quite unlike the parent rock.†

What I have said as regards lavas and the assistance which Chemistry has rendered to the study of them,

* Brit. Assoc. Report, 1880.

†Roy. Soc. Proceed., vol. L. (1891).

inclines me to the opinion that their origin does not depend upon one, but upon several causes acting together. When we set ourselves to explain the origin of minerals in rocks and metamorphoses of rock masses themselves, we should not, I think, limit our horizon by assuming any single cause alone as sufficient to bring about the effects; for, just as zeolites may be artificially made by more than one chemical reaction, so may they and all other rock-forming minerals be produced by more than one process in the laboratory of Nature; but at the same time we must guard ourselves against assuming that because the chemist has successfully reproduced rocks and minerals in a certain way, Nature has of necessity always—or, in fact, ever—employed the self-same means to bring about a similar result. The various forms of energy in Nature — heat, light, electricity, chemical action, &c.—do each play their particular parts, either individually, or more often in combination; and frequently to such an extent does the transmission of force occur, that it is very difficult to determine the agent which has had the predominating influence in producing a particular result. Thus, for example, Dr. Sorby has shown us that where solution is attended with contraction, pressure produced by the contraction will always promote solution. So again, the experiments of Spring of Liége have shown that extreme pressure alone (exceeding 7,000 atmospheres) can effect chemical change. Peat under a pressure of 6,000 atmospheres has been converted into coal with entire disappearance of its organic structure, and similar chemical changes were effected by Frémy by heating vegetable substances in closed tubes to a temperature of 3,000° C.

The application of chemical facts to the study of geological phenomena has led to the formulating of cer-

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The application of chemical facts to the study of geological phenomena has led to the formulating of cer-

tain hypotheses with regard to the age and history of the igneous rocks. The late Professor Forbes, one of the earliest chemists to direct attention to the study of chemical geology, draws four conclusions on eruptive rocks * :—

1. That the Plutonic rocks differ in chemical composition according to the age of appearance.

2. That intrusive rocks having identical mineral constitution have been intruded at corresponding geological epochs.

3. That the minerals in such rocks may serve to distinguish the several eruptions.

4. That where the epochs differ the intrusive rocks vary.

In considering questions of this kind we should bear in mind that the older a rock is the more frequent will have been its opportunities for alteration subsequent to its eruption.

Continental as well as the earlier English geologists have maintained that a sufficient difference of composition in volcanic rocks did exist to indicate difference of age, and the whole question is dealt with in the exhaustive paper by Allport on the British Carboniferous Dolerites (Q. J. G. S., vol. xxx).† Uncertain as may be conclusions arrived at with regard to the age of rocks erupted in bygone periods of the world's history from a chemical examination alone, geologists may possibly meet with more success from a study of the lavas erupted from the same volcano at different periods of its activity. Ricciardi,‡ analysing Italian volcanic rocks, has shown that their composition becomes modified in

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* Journ. Chem. Soc., June, 1868. "Chem. News," Oct. 23, 1868.

† Ward, Q. J. G. S., xxxi., 388.

‡ J. Chem. Soc., 1887, ii., 1023.

successive eruptions. Thus he states that the eruptive matter discharged from submarine volcanoes in past times was acidic, containing about 73 per cent. of silica, whereas the lava in more recent eruptions has a basic character containing but 48 per cent. of silica, and that Etna and Vesuvius have for the last three centuries emitted a product of constant composition and basic type.

A curious relation has recently been noticed by Lapparent* between the acidic eruptive rocks and the solfataras which are most abundant in volcanic districts, and are characteristic of the occurrence of acidic eruptive rocks. They are therefore rare near Vesuvius and Etna, where the rocks are basic, but abound in the Chilian Andes, Java, New Zealand, &c. Solfataras would seem to result from the gradual evolution of gases at one time incorporated with lavas and now given out. Acidic rocks being as a rule very refractory would retain the gases with which they were permeated at the time of eruption. The presence of gases in the lavas would retard the formation of crystals, but would tend to promote the growth of large crystals which characterise the acidic rocks.

In writing this address I have intended that my remarks should be suggestive of various lines of enquiry which in my opinion geological research may fitly undertake. Much of what I have put before you is pure hypothesis, but hypothesis is valuable when not allowed to outstep its bounds. Professor Blackie has said, "Imagination is the enemy of science only when it acts without reason," but in the researches to which I have directed your attention this evening there has been the union of hypothesis with experiment, in which, using the

* J. Chem. Soc., 1889, ii.

words of the late Professor Jevons, "The one great method of inductive investigation consists." Geology has entered upon a path of experimental synthesis which we may confidently expect will lead to the revelation of Nature's most profound secrets, and I cannot do better than close this address with a quotation from Leibnitz, written two centuries ago: "He shall perform an important part who shall compare products from the depths of the earth with those of the laboratory, for he will then discover the striking resemblance between the products of Nature and of art, for Nature is only art on a large scale."

THE MORAINE OF LLYN CWM LLŴCH, ON THE BEACONS OF BRECON.

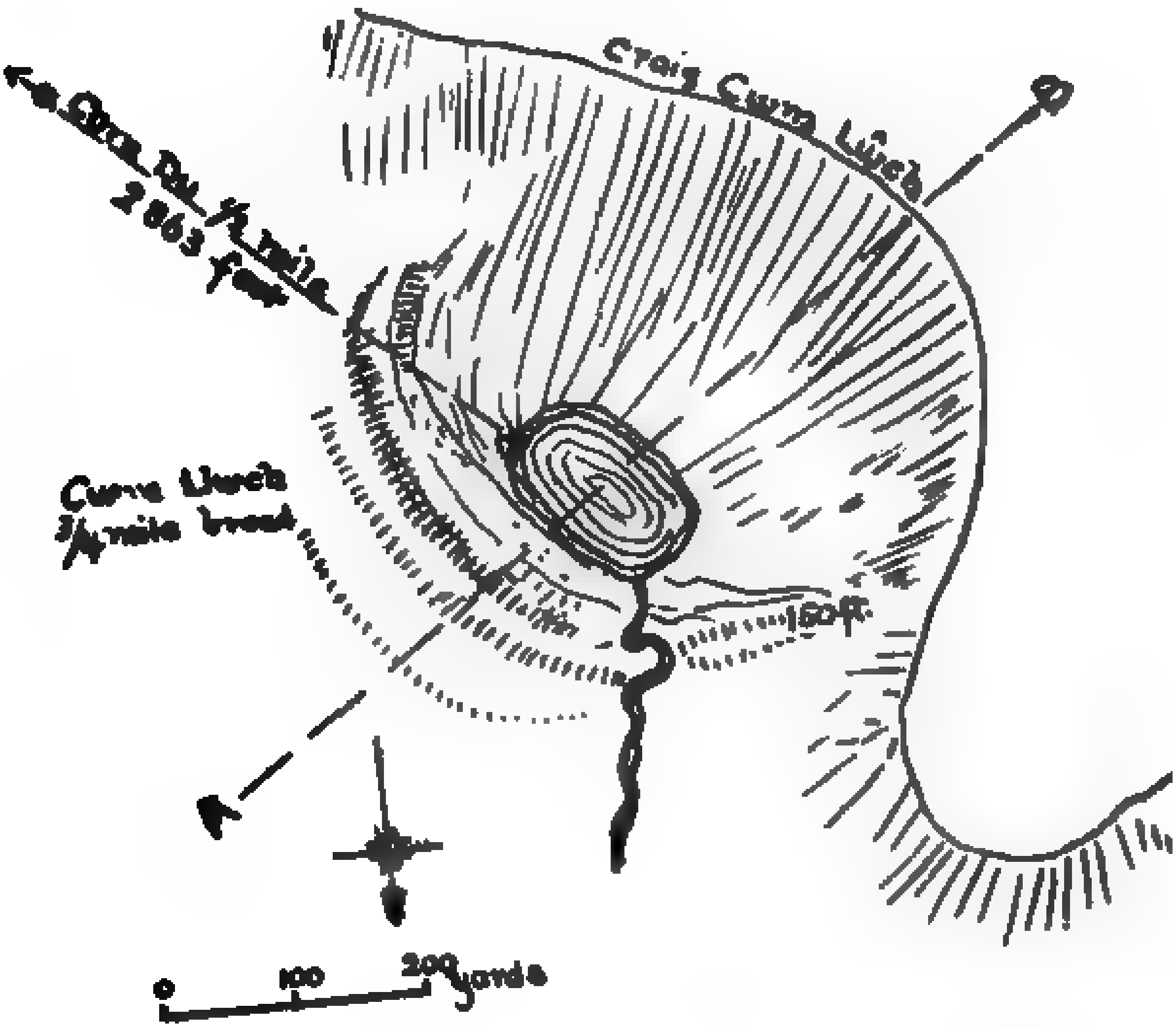
By T. Mellard Reade, C.E., F.R.I.B.A., F.G.S.

(*Read 13th November, 1894*).

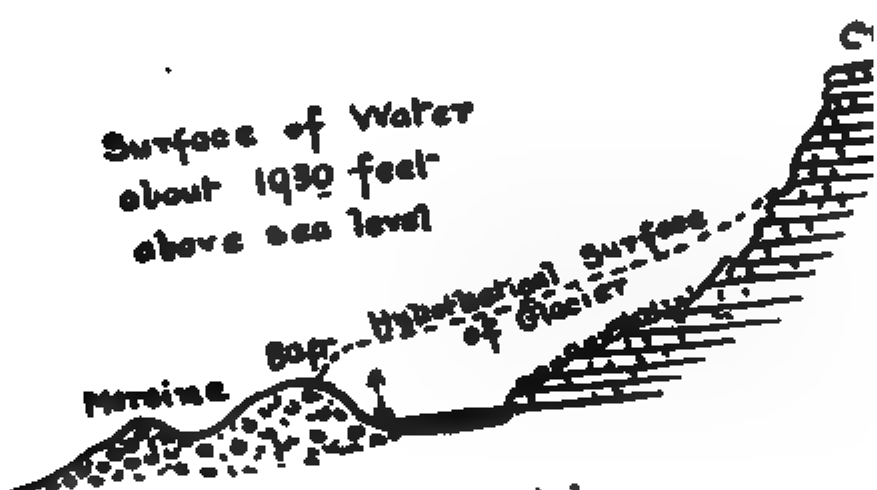
The Beacons of Brecon form one of the grandest examples of denudation in Great Britain. Composed from base to summit of nearly horizontal beds of Old Red Sandstone with intervening layers of Marl, they rise severally at Pen y Fan to 2,906 feet, and at Corn Du to 2,863 feet, above mean sea-level.

Though approximately horizontal, the beds have a southerly dip of from 2° to 3°, and it is quite evident that they are the remnants of an immense dome-shaped mass of Old Red Sandstone, which at one time has extended over Herefordshire and a considerable portion of Brecknock and Monmouth shires.

Lyn Cwm Llŵch and Morain
on the
Beacons of Brecon



Plan



Section
on line A.B.

The courses of the Rivers Wye and Usk show this as conclusively as do the continuity and horizontality of the beds of sandstone and shale. These rivers, flowing out of a country reduced to a base-level of erosion, cut through high ground composed of Old Red Sandstone capped with Carboniferous Limestone, forming the far-famed picturesque scenery of the Wye and Usk. Standing upon the terrace near the Royal Hotel at Ross and looking northwards over the plains of Herefordshire, or —still better—examining the Wye sweeping round its tortuous course, charging, emerging, and re-entering the elevated limestone plateau of which Symonds' Yat is to tourists one of the best known localities, it becomes evident to a student of Physical Geology that the river had its birth when the whole of Herefordshire was covered with this dome of sandstone capped with Carboniferous Limestone, and perhaps Coal Measures. It commenced to flow from a level much higher than any of the hills of the plateau it appears now to charge and cut through. The entire district has been reduced in height throughout its whole extent, the denudation working southward against an escarpment of which the narrow ridge of the Beacons is the remnant.

The shaded and geologically coloured maps 42 S.W. and 42 N.W. show this pretty clearly.*

It will be observed that there are four great semi-circular-headed Cwms gouged out of the escarpment, viz., Cwm orgwm, Cwm cynwyn, Cwm serre, and Cwm Llwch, lying parallel and opening out to the North-East, and in the latter is situated Llyn Cwm Llwch, a small tarn or lakelet which, with its embanking moraine, is the subject of this sketch.

* After writing these lines I was pleased to see that Ramsay, in his "Physical Geology and Geography of Great Britain," 5th Edition, p. 500, has given an almost identical explanation of the physical features of the Wye and Usk and the Beacons of Brecon.

At first sight it seems very singular that this lakelet and moraine should be here at all, nestling as it does under the steep cliffs to the westward, when neither lake nor moraine are to be seen in the three other Cwms not very different in size or shape, as may be seen from the shaded ordnance map. Before venturing upon an explanation of this phenomenon, it will be necessary to describe the Llyn and its embankment.*

The breadth of Cwm Llwch, measuring in a north-westerly direction, is about three-quarters of a mile; but the lakelet lies under the westerly cliffs, and not more than a furlong from them, measuring horizontally from the summit ridge. The lakelet cannot be more than 150 yards in its greatest diameter, which lies in a north-westerly direction. It will be seen, on reference to the accompanying Plate, that the cliffs called Craig Cwm Llwch bend round to the north-eastward.

The moraine of this little tarn is of a surprisingly perfect character. It is built up in an embankment, which encloses this small section of the Cwm in a very regular manner. Its base is in the valley bottom, the material consisting of angular blocks of Old Red Sandstone, while the steepest part of the inside slope is 30°, and the outside slope 27°. The highest part of the moraine in front of the lakelet is 80 feet above the water level, but as it runs north-westerly it creeps up the hill to a height of about 150 feet, where it shades off to nothing.† There is

* Symonds has a reference to this tarn and moraine in "The Records of the Rocks," p. 247.

† It is interesting to find that moraines formed of Andesite boulders piled upon each other mark the former extent of the glaciers of Mount Kenya, in East Africa, situated nearly on the Equator. These moraines occur at an altitude of 10,000 feet. They are about 30 feet high, and reach nearly across the valley. (Dr. J. W. Gregory, Q.J.G.S., Nov., 1894, p. 520.) It will be observed that our miniature example is over twice this height.

on the lowest side of the moraine what may be called an apron of drift, which continues in a wave-like form lower down the valley. The transverse section I exhibit (see Plate) will show this. The moraine, when looked at from above, is strikingly regular; but on nearer examination it is found to bifurcate into two ridges at the south-east end, where it joins on to the sloping foot of the cliff, but in a less marked manner than at the north-western end. Without a cutting into the moraine, it would be difficult to say if the interstices of the blocks are filled up with clay and detritus; but probably they are. The surface is grass-grown. There is an outlet for the water of the lake naturally cut through the embankment, as shown in the map.

To anyone who has actually seen a glacial moraine, there is no mistaking its character. The frontal part of the moraine may be called the terminal moraine, but as it creeps up the hill to the west it becomes a lateral one. The direction of the ice-flow seems to have been E.N.E., or partly *across* the valley. There were no striated stones to be seen, and the moraine possesses all the characteristics of an existing Alpine moraine.

So much for the facts, but let us meditate on the cause. Firstly, the lakelet and enclosing moraine are under the steepest cliffs, which are so disposed as to shut off the sun's rays for a longer period of the day, at the time when they are most powerful, than is the case in any of the other Cwms. The difference of these conditions is not strikingly great, but it is sufficient, and embodies a lesson on the surprising effect sometimes arising from small differences. When once the idea is fully grasped on the spot, it is plain to see that the sun has traced out this moraine, and settled its alignment and position in the larger Cwm or valley. It is as though an

artificial bank had been built by man—not across the neck of a narrow valley, like our Vyrnwy dam, to retain the water thereof, but in a sweeping curve on plan, joining up to the foot slopes of the cliffs with quickening curvature at either end.

The form, direction, and position of the moraine were to me quite a revelation of the sun's determining power in the tracing out and building up of this remarkable and substantial bank.

The lakelet is of precisely the same character as the Loughs Bray described by me in a paper on the "Dublin and Wicklow Drift" published in the "Proceedings" of this Society last year (p. 201 and Plate 4). It is, however, much smaller, although the moraine at its highest part is as much above the water of the lake as the moraine of the Upper Lough Bray figured in that Section. The mass of the moraine is, however, much smaller, and the blocks of rock not comparable in size with the huge granite blocks of the Upper Lough Bray. It is, however, more peculiar, and one Corry helps to explain the other.

These moraines are not "talus" moraines, like Cwm-du in North Wales,* but are real glacier—or perhaps it would be more correct to say "glacierette"—work: that is, the blocks have travelled on moving ice, to be tipped in a way to build up an embankment.

The origin of these Cwms or Corries is a much-debated question. Some hold that they have been entirely excavated by ice. To my mind they ante-date the Ice Period. We have seen that the Brecon Fans or Beacons are the remnants of a vast denudation dating from millions of years before the Ice Age. That ice has

* See "The Drift Beds of the Moel Tryfaen Area of the North Wales Coast," p. 57; and for Section, Plate 6, Fig. 17.

had influence in modifying and emphasising the forms of these semi-circular escarpments, it would be folly to deny. The effect of ice lingering in a corner of one of these Cwms would be to preserve its precipitous character and prevent it from getting covered with talus material, for such material would, instead of accumulating at the foot-slope, be carried onward to form the moraine.

In consequence of this clearing away of *débris* as quickly as formed, there would be a tendency for the precipitous sides to be eaten backwards in Corry form.

It has been remarked that these glacial tarns, with their moraines, are usually situated on the north or north-east sides of the mountains on which they are located, and in elevated positions. As they are the last lingering remains of the Glacial Period, the reason is obvious, for it is only here that "nestling" glaciers—as Mackintosh calls them—could exist, and they seem to have lived for a long time, judging by the immense mass of materials accumulated in their moraines, as represented by those of Loughs Bray and Llyn Cwm Llwch.*

During my stay at Brecon I looked for other signs of glacial action, but they are not numerous or striking. It is true that there are many large boulders—mostly varieties of grit or sandstone—lying about the country which point to glacial action as a means of transport, but I could find none that were planed or striated, and no foreign blocks. There was a section of drift exposed at Aberbran Station in a cutting for a siding, which I examined, but from its local character it may be river

* In this connection it will be well to read Mackintosh's observations on Cwms ("Scenery of England and Wales," pp. 184–204). Although many of his explanations are fanciful, he was a good and accurate observer. Also see Sir A. Geikie's "Scenery of Scotland," 2nd Edit., p. 157 and p. 165; and the chapter on Cwms and Corries in Ireland, in the "Manual of the Geology of Ireland," by G. H. Kinahan, pp. 309–313.

drift, or it may be a deposit of glacial waters; but here again we could find no glacial markings on the boulders, which did not reach a large size, and the sand was angular. Most of the stones were well rounded, and all of sandstone of one sort or another—red, yellow, or brown, coarse or fine in grain.

Notwithstanding this absence of distinct ice-markings, there is little doubt that all these valleys have at one time been filled with glaciers.

The alluvium of the River Usk, as of the Wye in Herefordshire, is a fine red loamy sand, containing in places patches and groups of pebbles, the stones sometimes being arranged vertically. The whole of these phenomena constitute, in my view, a very interesting episode of the close of the Glacial Period.*

NOTES ON THE GEOLOGY OF THE COUNTRY BETWEEN PRESTON AND BLACKBURN.

By E. Dickson, F.G.S.

(*Read 8th January. 1895*).

As far as I have been able to ascertain a paper has not been read before this Society dealing with the district which I propose to treat of this evening.† In the present paper I intend merely to set forth the main

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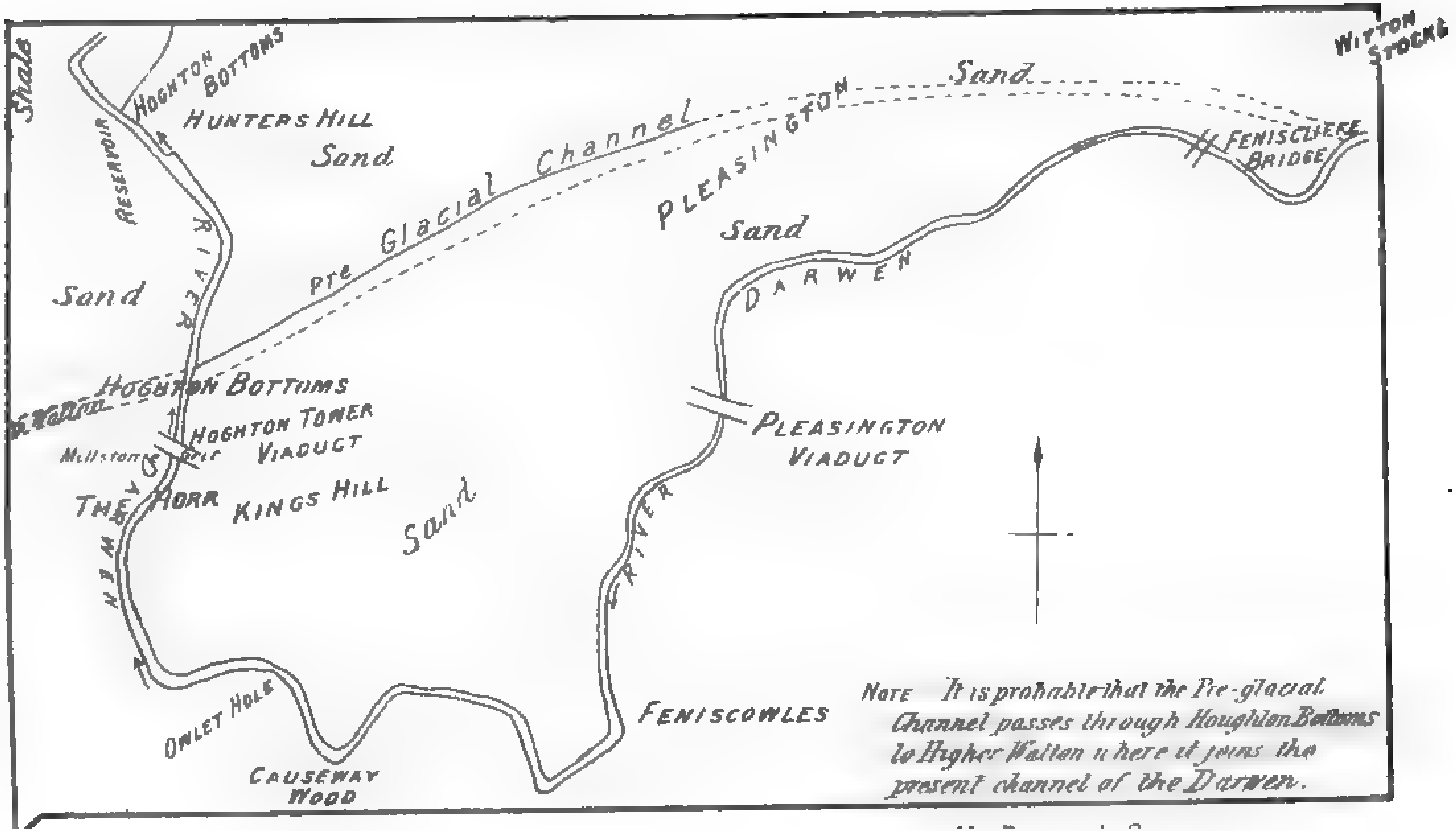
* Since this paper was written a very interesting and instructive article entitled "The Recent Irish Glaciers" has appeared in the Irish Naturalist (Nov., 1894, p. 236), from the pen of the veteran geologist G. H. Kinahan, in which he shows how ridges and stacks of blocks accumulate at the present time in the mountains of Galway. Mayo, and Wicklow during the winter. A deep drift of snow settles in a hollow or under a mountain cliff, and blocks and smaller detritus slide down its surface to settle at the margin. This is a true talus moraine, whereas what I have been describing is a genuine, though miniature, glacier—a "Corry glacier," according to the nomenclature of the Rev. M. H. Close.

† The District is comprised in the "Geology of the Burnley Coal Field" (Survey Memoir).



Shale
Hoghton Bottoms
Reservoir
Hunters Hill
Sand
River
Sand
Pre Glacial Channel
Pleasington
Sand
Witton Stocks
Fenisclife Bridge
Sand
Darwen
Hoghton Bottoms
Hoghton Tower Viaduct
Millstone
The Horr
Kings Hill
Sand
Pleasington Viaduct
River
Darwen
Owlet Hole
Causeway Wood
Feniscowles
Note It is probable that the Pre-glacial Channel passes through Houghton Bottoms to Higher Walton where it joins the present channel of the Darwen.

features of the geology, omitting details which may, on some future occasion, be the subject of a further communication. In any case it seemed to me to be the better plan to give you first a general outline of the country, in order to more readily describe the detailed sections on some later occasion.

The district I am about to describe comprises an area of about fifteen miles in length, by seven or eight miles in width. It lies altogether in the valley of the Ribble, the line of watershed dividing the Ribble area from that of the Mersey having at its nearest point Darwen Moor, a few miles to the south of the district.

The geology naturally divides itself into an examination of

(1.) The Triassic rocks situate to the west of the great fault running north-west and south-east dividing the Triassic trom the Permian and Carboniferous rocks;

(2.) The Permian and Carboniferous rocks;

(3.) The glacial deposits which cover so wide a surface of the whole area, and form so characteristic a feature of the country in question.

The series of faults which pass through the district have to a very great extent decided its physical features, as well as determined and affected its structure. The following are the four main faults to which I shall allude from time to time.

(1.) A fault to the west of Preston, dividing the Pebble beds from the Keuper, the throw of which has been estimated at 750 yards.

(2.) A fault to the east of Preston, running in a north-easterly and south-westerly direction, dividing the Trias from the Carboniferous and Permian rocks, of which the throw has been estimated at about 350 yards.

(3.) The great fault to the east of Anglezark Moor and to the west of the Liverpool Waterworks Reservoir, separating the basement beds of the Kinder Scout or lowest division of the Millstone Grit from the Gannister beds or Lower Coal Measures. The throw of this fault is greatest near Brinscall Hall, at its north-east end, where it reaches 4,000 feet, and brings the lowest beds of the Kinder Scout against the Coal Measures.

(4.) The Irwell Valley fault, which runs in a north-westerly direction to the west of Withnell Moor, along the course of the Roddlesworth.

In addition to these main faults there are numbers of smaller faults, which affect the inter-relation of the various members of the Millstone Grits series, as also the Gannister beds and the Yoredale rocks. Part of the district, namely, that lying to the north of Hoghton, shows evidences of the Clitheroe and Skipton Anticlinal, (one of the three principal anticlinals which form the great compound upheaval of the lower and earlier rocks), dividing the Burnley Coalfield from the Ingleton Coalfield to the north. The direction of the Clitheroe and Skipton Anticlinal has been put by the Government Surveyors at east 35 north. The western extremity of this great anticlinal is to be seen in a very interesting section at Roach Bridge in the Darwen Valley, whence it runs north-east, passing by Mellor and Wilpshire Station, into the valley of the Ribble, next past Clitheroe, Downham, and eventually to Bolton Abbey. This anticlinal has a total length of from 30 to 40 miles. Another great anticlinal runs to the north of the Longridge Fells, along the valley of the Loud, and by the village of Slaidburn. In addition to these greater anticlinals, there are several smaller ones, one for example to the east of Bamber Bridge, bringing in a small area of the Coal Measures.

It is a curious fact that the anticlinals should generally form valleys, and the synclinals ridges between them. Sections in the Trias are not very commonly met with, inasmuch as the country is, for the most part, covered by a thick coating of drift. Borings show that the rock beneath the drift is of remarkably level surface, forming a true plain of marine denudation. Much of the rock in inland districts is below the low water level, so that the only sections in the Trias are to be found either in the beds of the Ribble or of the Darwen, and in a few streams. As one approaches the more elevated districts sections are naturally more abundant, but much of the lower lying country is obscured by thick deposits of drift, much of it glacial sand. The river valleys in the higher part of the district I am describing are, for the most part, excavated along the strike of the shales which come between the layers of sandstone and grit of the Millstone Grit and Yoredale series. The capping of grit on the summits of the Pendle Range has undoubtedly preserved the underlying shales from denudation. This coating of grit on the hill tops forms a plain of marine denudation, out of which the valleys have been denuded: for example, the wide valley between the Longridge Fells and the Pendle Range. As a result of the numerous faults, the older rocks are contorted and disturbed to a very considerable extent, as might have been predicted would have been the case. It is interesting to note of the section near the waterfall at Bannister Hall, that evidence appears that we have there reached the eastern margin of the great plain of marine denudation underlying the drift. The fells in the neighbourhood of Hoghton form part of the Pendle Range. This range elsewhere consists of a double ridge of grit stone with valleys between them; but from Hoghton Tower Hill to

Whittle-le-Woods the grits form but one ridge, the lower lying rocks not being brought up by the anticlinal, which here ends abruptly. The Lancashire plain commences immediately to the west of this ridge.

I have now given you the principal physical features of the district, and have called your attention to some of the causes which have contributed to make and to mould those features. I will now briefly lay before you some of the features which characterise the various rocks of the district, and will refer you to some of the principal sections in which they appear.

The oldest rocks occurring in the district I am speaking of are the series of sandy shales and grit lying above the Bowland Shales, and now collectively known as the Upper Yoredale Grit. Many of you are well acquainted with these grits since they supply the well-known building stone obtained from Longridge. These beds also form the summit of Pendle. They consist of sandy shales, grit, and sandstones, frequently alternating and changing into one another. Plant remains are found in them, but are not abundant. The grit varies considerably in texture, being for the most part fine grit frequently passing into conglomerate. It consists of very small, rounded grains of white quartz in a felspathic matrix with interspersed plates of mica, and is generally of a white or light yellow colour. In the district we are now considering, this rock is seen near Mellor Brook, along the banks of the brook, and this spot is the most westerly point of the Clitheroe anticlinal where it is visible. The dip of the rock in the brook is north, whilst in the quarry at Resburn Fold, close by, the dip is south, giving the position of the anticlinal. At Lower Abbot House the dip of the rock is 20° north, the fault here taking the place of the anticlinal.

Sections in the Yoredale grit are seen in the quarry at Harwood Fold, Mellor Moor Edge, and in the railway cutting to the north of Wilpshire Station. One of the most interesting sections in the district is that in the Yoredale grit at the south end of the tunnel, near the station, which shows beds contorted and repeated by an east and west fault, the beds being pushed over laterally on each other. At the north entrance of the tunnel there is also an interesting section, the beds forming a complete ridge, thus indicating the position of the axis of the anticlinal.

Above the Yoredale rocks occur the important series known as the Millstone Grit, which has been separated into four divisions, 1st, 2nd, 3rd, and 4th grits, by having beds or series of beds of shales intercalated, each grit consisting of a bed or beds of sandstone or grit, separated by layers or beds of shale. The general characters of the grits are more or less similar, so that it is difficult, if not impossible, to distinguish them the one from the other, or indeed to distinguish them from the Yoredale grits purely on lithological grounds. I consider these grits would well repay a more exhaustive examination than has, I believe, been yet accorded them.

The lowest of the series is a grit known as the Kinder Scout grit, which consists of two beds of grit separated by shale. These grits vary in coarseness from a conglomerate to a sandstone, and in colour from a light yellow to brown. The conglomerate consists of pebbles of white quartz in felspar, with particles of mica interspersed. Plant remains are by no means uncommon throughout the grit beds. Some of the quarries have yielded some of the type specimens figured by Professor Williamson in the volumes issued by the Palæontographical Society. The upper beds frequently contain

coal seams from eight to fourteen inches in thickness, which have been worked in places. The most westerly point at which the Kinder Scout is found, is at Hoolster Hill, about three miles north of Hoghton Tower, where it forms the elevated moorlands known as Withnell Moor, Bromley Pasture, and Anglezark Moor. Good sections are to be seen on the eastern side of Anglezark Moor, where the basement beds consist of coarse yellow grit and conglomerate. Overlying these basement beds are other beds, also of grit, though not of so coarse a texture, separated by beds of shale. The Kinder Scout forms the elevated ridge stretching from Hoolster Hill to Pendle, and has there an average dip of 35° S.E. The moorland known as Withnell Moor, which attains an elevation of 1,249 feet, is bounded by the two great faults to which I have before referred, the Irwell Valley Fault on the east, and the Anglezark Fault on the west. The former is well shown in a section under a bridge crossing the brook at Belmont, and the latter fault at Dean Wood, near Rivington. As I have said before, the throw of the fault opposite Brinscall Hall is 4,000 feet, the Coal Measures being brought against the Kinder Scout beds. Overlying the Kinder Scout occur a thick series of shales with grit bands, known as the Sabden shales, so called from a place in the Ribble Valley, where they are exceptionally well developed. The shales frequently contain layers of ironstone nodules, which are fossiliferous. These shales are largely developed in the Darwen Valley, and are visible in Hole Brook, west of Hoolster Hill, and in the Darwen below Samlesbury Mill, where they attain a thickness of 625 feet, and have a dip of 40° S.

The division of the grit known as the Third Grit is also fairly well developed in the district. It con-

sists of two beds of sandstones and conglomerates, separated by beds of shale. It is very difficult to distinguish this grit from the Second Grit, or Kinder Scout, and this can only be done by following the beds, and studying carefully the physical conformation of the country. In the south part of the district this Third Grit is to be seen near Belmont in the stream below the Reservoir, to the east of the Irwell Valley Fault. In the northern part a good section is to be seen in the Darwen to the south-east of Samlesbury Bridge, where the grits are contorted, and the interposed shales contorted and faulted. At the junction of the Arley Brook and the Darwen, the dip is reversed, owing to the effect of a neighbouring north and south fault. At Woodfold Park, half-way between Mellor and Hoghton Tower, an excellent section is seen of the upper beds, consisting of dark blue clay with nodules of fossiliferous ironstone, which has received the name of Alum Scar, from the fact that alum was formerly obtained from these shales. Another good section of the Third Grit is also to be seen on the railway from Blackburn to Clitheroe, about 2½ miles from Blackburn, where the lower bed of the grit is observed to be violently contorted. Towards the easterly part of the exposure of the Carboniferous rocks, the same grit rocks are seen east of the north-west fault passing through Chorley and Whittle, and running into the main north-east and south-west fault. The grits are here visible in a small brook above the canal at Radburn, where they dip 10° in a south-easterly direction, also near the high road from Whittle to Brindle. Again in the Gorton Brook, near Duckworth House, distant two miles from Bamber Bridge Station, the beds dip 20° north-west, whilst about 400 yards in a south-easterly direction, the same beds are seen dipping

5° or 10° south-east. A small fault to the east, near Jack Green, in Mill Brook, also throws up the same beds; goniatites and other fossils being noticeable in the shales.

The Second Grits, so well represented in the Haslingden Valley, and commonly known as the Haslingden Flags, are not as well developed in this district as are the other members of the Millstone Grit series. They are to be seen in the valley below the Anglezark lead mines, and on the south and west sides of Rivington Pike, as well as at Tock Holes, and in the bed of the Roddlesworth. They consist of gray sandy shales, with or without flag stones, and are micaceous, fine-grained, ripple marked, and frequently bear carbonaceous markings.

The uppermost member of the Millstone Grit series, the First Grit or Rough Rock, is exceptionally well-developed in this area. At Hoghton Tower it attains a thickness of 400 feet; indeed it is stated to be thicker here than in any other part of Lancashire, or possibly the north of England. The hill upon which Hoghton Tower stands rises to a height of about 580 feet, and has a deep ravine on its easterly side, which the railway from Preston to Blackburn crosses. The Rough Rock consists of a coarse grained grit, frequently passing into a conglomerate of white quartz pebbles in a felspathic matrix. The rock is often soft, and from the ease with which it breaks up into sand is frequently called sand rock, although at Hoghton it is the reverse and consequently largely quarried for building purposes. Its westerly extremity is near Whittle, and it runs as a ridge from there south of the Pendle Range to Colne. The Rough Rock also appears in the high ground above Pleasington Revidge and Billinge, and again at Withnell, north of the Anglezark Fault. As will be seen from

the map (89 N.W.), there is a small exposure of Permian to the east of the north-east fault, about two miles east of Walton-le-Dale. The sections are few, most of the rock being obscured by drift. The section of Permian Rock at Roach Bridge shows a thickness of about 230 feet, resting on the denuded edges of the Carboniferous rocks. They consist of beds of red and yellow sandstones, with layers of red marl at the base of each bed, overlying a fine conglomerate containing pebbles from the Millstone Grit. I am not aware that any fossils have been found in these Permian rocks, but I think that a careful examination of the marls below the sandstones would lead to the discovery of Permian fossils, as it has done at Skillaw Clough. As the Permian rocks rest on the denuded edges of the Carboniferous rocks, it would seem that the Carboniferous rocks received their dip and suffered denudation before the Permian rocks were laid down.

The last of the older rocks that I shall deal with are the Pebble beds of the Trias, which have been thrown down by the great north-east and south-west fault. For reasons which I have before given, sections in the Trias are not abundant. Between the north-east and south-west fault and the fault which brings down the Keuper marls the red sandstones belong to the Pebble beds. The rock is usually of a hard red sandstone, and contains few pebbles. It is seen in various places along the banks and in the bed of the Ribble, and it is out of these beds that the new Dock at Preston has been excavated. The rock is exposed in the Ribble near the wooden bridge known as the Tramroad Bridge, where it has a dip on the westerly side of the bridge of 20° south-east and on the easterly side of the bridge 12° south-east; but at a distance from the bridge of about two miles the rocks at

Walton-le-Dale, below the Church, give a south-westerly dip, so that, as the late Mr. Binney pointed out, the beds to the east of Preston dip in a synclinal curve. The sandstones as a rule are much current bedded, and contain a few coloured quartz pebbles. Several good sections are to be seen in the Ribble at Mete House, Seed House, and in the Darwen at the waterfall near the Bannister Hill Print Works, to which allusion has already been made. I regret that time will not allow me to deal with the drift deposits of the neighbourhood, interesting as they are, but I should like before I conclude to mention one fact to which my attention has been called by Mr. Shortt, the Vicar of Hoghton, who has given the subject considerable thought. If you will look at the 6-inch map of the Hoghton district you will notice what a remarkable curve the river Darwen takes in its course, after passing Feniscliff Bridge, and before it enters the valley running under and to the east of Hoghton Tower. Between Feniscliff Bridge and Hoghton Bottoms the intervening space is filled with masses of glacial sand, the banks rising to a height of 350 feet. Mr. Shortt considers he has evidence to show that the pre-glacial course of the river was in a straight line from the point where the stream now begins to diverge to the point where it enters the valley under Hoghton Tower, and that after the close of the glacial period which caused the deposition of these immense masses of sand the river's course became diverted thereby, and to reach its former channel it had to cut a channel for itself through the Millstone Grit to a depth of about 120 feet. It would seem at first sight that such a feat were almost impossible, but as a case in point I will refer you to observations made by Dr. Geikie on the excavating powers of certain rivers in the south of Scotland, where

the same thing has actually happened as may be predicted to have happened as regards the Darwen. "Along the banks of the Esk at Edinburgh nothing can be more striking than the sudden change of scenery which ensues upon the passage of a stream from its new into its old channel. In the former the water frets and fumes between lofty walls of rock which appear to rise vertically from the river's bed. In such a deep narrow gorge the stream may continue to flow for miles, when of a sudden the precipitous cliffs abruptly terminate and the water escapes into a broad vale, with long sloping banks of clay, sand, and gravel. After winding about in this open glade, it may be for several miles, the stream not unfrequently leaves again as suddenly as it entered, and dashes once more into another dell whose walls of rock shoot up as before. The broader portion of the valley is that part of the old preglacial channel which the stream has re-excavated, while the narrow gorges are entirely new cuts which the present stream has excavated since the glacial period."—("Great Ice Age.")

I have quoted the above at some length, as it exactly describes what has taken place and is taking place in the case of the Darwen, and the above description might have been written of the Darwen itself.

If the surmise that the Darwen since the glacial period has cut out a gorge 120 feet deep be correct, we must enlarge our estimate of the rate at which water can cut channels through sedimentary rocks.

NOTE BY THE REV. J. SHORTT.

The sand reaches in two knolls, one called the "King's Hill," the other "Hunter's Hill," the height each of 350 feet. That the sand is of the middle drift is shown by its including at the Railway Bridge at "Long Barn" the usual shells, such as *Turritella communis*, &c. The

length of the Darwen, exclusive of windings, is 11½ miles; inclusive of windings is 17⅝ miles. From the bend of the Pleasington, where it commences the detour, to its nearest point in Hoghton, is 1 mile, 147 yards. The length of the actual (excluding windings) course is 2¾ miles. It drains 36,480 acres. The area of its basin is 57 square miles.

Its ability to excavate the gorge, called in Hoghton the "Horr," is due to the Millstone Grit containing layers of shale. These weather more readily away than the grit itself, which, being thus undermined, topples over into the bed of the stream.

All along its course are terraces showing that it has flowed at higher levels. Its present level in Hoghton is 190 feet, or about 100 feet lower than at the bend in Pleasington. The Boulder Clay is the upper, and I fancy that the lower is to be found in the Churchyard at Higher Walton. It is of a darker colour, and more tenacious than that found here.

The origin of the name "Horr" is the same as that of Horwich. "Hoher"—Higher, the gorge being in the Higher Park, the adjoining farmhouse being still known as the Higher Park Farm.

NOTES ON SOME FOSSIL PLANTS FROM DOULTON'S DELPH, ST. HELENS.

By Joseph Lomas, A.R.C.S.

(Read 8th January, 1895.)

Doulton's Delph is a large excavation in the Middle Coal Measures, and is situated in the south-west part of St. Helens. A section of the strata is given in Morton's "Geology of the Country around Liverpool," and a list of twenty-three species of plants is appended.

Owing to the constant quarrying of the rock, fresh surfaces are exposed almost every day.

Frequent visits show that the facies of the flora changes with the strata. At one time ferns may predominate, at another the prevailing organisms may be those associated with Lepidodendra. Several large trunks of Sigillaria, with their attendant Stigmaria, were visible recently. Some of them were over three feet in diameter. Pieces of stems also lie about the floor of the Delph—the remains of trees which have been excavated.

In October of last year the fossils were nearly all such as would be expected in the vicinity of a grove of Lepidodendron trees.

Stems of L. obovatum and L. gracile were very abundant. Some of L. obovatum were over a foot wide, and somewhat flattened.

The tender terminal branches (Lycopodites) were also met with. Roots resembling Stigmaria were associated with the stems. In all probability, the forms called by that name belong to Lepidodendra as well as Sigillaria.

The internal casts of the stems (Knorria) as well as Halonia, occurred in the same place.

The most interesting point, however, was the extraordinary abundance of the fruit cones (Lepidostrobi). One slab not more than a foot in diameter showed a stem which bifurcated after a few inches, and each branch was then terminated by a Lepidostrobus.

Among the troubles which students of fossil botany meet with, is the dissociation of the various parts of the same plant. It is very satisfactory then to meet with such specimens which tend to show, without doubt, the affinities of parts which in some cases have received different names.

The Lepidostrobi occurred in all stages of ripening. One ripe specimen was six or seven inches long, and even then the termination was not shown.

Another, about four inches long, was calcified, and showed structure to the minutest detail. On the outer surface it had the appearance of overlapping scales arranged alternately, and climbing round a central stem in a low spiral. In the middle of each scale, and lying close to the under-surface, a slender club-shaped projection is seen.

In cross section the cone appears circular, and the circumference is seen to be made up of six scales.

Each scale (Lepidophyllum) is bent sharply at right angles at the place where it is overlapped by another. On turning inwards it first contracts and then widens a little again just before joining with the central stem. The club-shaped projection (ligule?) also expands into two wing-like projections as it approaches the interior.

But perhaps the most instructive appearance of the specimen is obtained by making a longitudinal section of the cone. In the centre the axis is seen, showing rhomboidal marking not unlike those on the stem of Lepidodendron. The vascular bundles are exhibited as minute capillary tubes, which branch out and enter the scales at the sides. Resting on the scales are Sporangia. Some of these showed microspores *in situ*. I could not, however, make out macrospores with certainty.

The ligules mentioned above as lying in close contact with the under-surfaces of the scales, are seen in longitudinal section to be really projections from the upper parts of the lower scales. From their attachments they bend upwards and inwards until they approach the under-surfaces of the scales above.

Loose Lepidophylla are contained in the matrix, and microspores can be detected also scattered through the mass.

So far as I know, the club-shaped projections (ligules?) described above have never been mentioned as occurring in Lepidostrobi, unless the scales figured by A. Brongniart ("Hist. des Vègét. Foss.") from specimens in the Oxford Museum are their representatives.

The class Lycopodinæ is divided by some authors into two orders, Lycopodiaceæ and Ligulateæ. The former includes the Lycopods proper, while the latter includes Selaginella and Isöetes. Lepidostrobus seems to partake of the characters of both orders, resembling the first in the general form of the fruit cone, and the second in possessing a ligule and in being heterosporous.

On another visit to the quarry there seemed to be a preponderance of plant remains appertaining to Calamites.

Besides several species of stems, Calamites decoratus (terminations with rootlets), C. cannaeformis, C. approximatus, &c., the foliage occurred as Asterophyllites tuberculatus, Annularia and Sphenophyllum, and the rootlets as Pinnularia.

Among other fossils found were Cordaites, Trigonocarpum, many species of ferns, and several Algæ. One of the Algæ consisted of filamentous threads, branched dichotomously, and probably a species of Chondrites. Another spread as a fine film over a surface of shale. It contained no vessels, but darker curved bands sprung from one point at the side. In general appearance it resembled Delesseria.

Most of the specimens described are now in the University College Museum.

The above notes are crude and imperfect, as I have

neither the time nor the special knowledge to describe all the specimens in detail. They are only made in the hope that someone may be induced to work out the flora at Doulton's Delph in a thorough and systematic manner.

GEOLOGY OF THE FARÖE ISLANDS.

By Joseph Lomas, A.R.C.S., Special Lecturer on Geology, University College, Liverpool.

(Read 12th February, 1895.)

Introduction.

The Faröe Islands possess an unenviable reputation for fog and rain. Washed by the waters of the Gulf Stream, as is evidenced by the amount of drift wood and West Indian seeds which are found on the shores, they enjoy an equable, though wet, climate. Moisture-laden winds from the south-west are chilled by contact with the mountains, and it is seldom that the high grounds are visible from the coasts.

Fortunately, during our stay, the Islands did not hold good their reputation, and but little inconvenience was experienced on account of fog and rain.

The visit was made in July, 1894, and I was accompanied by my friends, Dr. Grossmann, of Liverpool, and Dr. Cahnheim, of Dresden.

My acknowledgments are due to these gentlemen for much valuable help.

The glacial features are but outlined here; a fuller account is published in the Glacialists' Magazine of June, 1895.

There being practically no roads in the Islands, travelling is by no means easy. The rugged character of the interior renders walking almost impossible except in a few places. All communication is carried on by open boats. The Faröese are very expert boatmen, and in travelling they take advantage largely of the strong tidal currents which run along the shores and through the fiords.

Some of the islands are inaccessible for a large part of the year. We may consider ourselves fortunate in being able to visit Fuglö and Myggenaes, although the latter was not reached without some exciting experiences, and at considerable risk.

Myggenaes possesses but one landing place, a ledge of rock at the side of a small bay opening towards the

south-west, and exposed to the full fury of the Atlantic waves.

The inhabitants we found to be very hospitable. They still retain their characteristic and picturesque form of dress, and their manners are very primitive. Stone anchors are in use in some of the more distant islands, while hand querns and other implements which with us are just beginning to find a place in our museums, as relics of a bygone civilisation, are used almost everywhere.

LITERATURE.

Comparatively few papers have been written on the Geology of the Faröe Islands, and of these the majority give prominence to the southern island Suderö, and its coal-bearing strata.

Many references are made to the islands in books of travel, but they seldom give anything of geological interest.

Lucas Debes. "Fœroa reserrata," Kiobenhavn (1673), mentions the occurrence of coal in Suderö.

Henchel. 1777-79. MSS. in Royal Danish Archives, reports on coal deposits.

Jorgen Landt. "Forsog til en Beskrivelse over Fœroerne," Kiobenhavn, 1800. Eng. Trans., 1810.

Sir George Mackenzie. "An Account of some Geological Facts observed in the Faröe Islands." Trans. Roy. Soc. Edin., vol. vii., p. 213.

The object Sir George Mackenzie had in view was to ascertain if the Trap was the result of submarine volcanic action. Gives an account of the physical features of the Islands, describes a specimen of ropy lava from Naalsö, and mentions evidence of flow structure in Eyde (Osterö) and Waii (Bordö). He concludes in favour of submarine deposition, on account of the

slagginess of upper and lower surfaces of lava streams. He mentions the occurrence of dykes, often with vitreous coverings, and thinks the separation of the Islands is due to the removal of dykes.

Thomas Allan. "An Account of the Mineralogy of the Faröe Islands." Trans. Roy. Soc. Edin., vol. vii., p. 229. Accompanied Sir George Mackenzie. Gives an admirable account of the Zeolites found. Describes the varieties of Trap, and mentions a remarkable columnar bed in Naalsö, which shows an arrangement of small prisms set at right angles to the axes of the vertical columns. Suggests that the whole mass was soft when injected by dykes. He does not share Sir George Mackenzie's belief that the lavas were laid down under water, but attributes them to surface lava-streams, the po-ition of the neck not being evident. He also refers to the scooped and polished appearance of the rocks, but does not suggest glacial action as the cause.

W. C. Trevelyan. "On the Mineralogy of the Faröe Islands." Trans. Roy. Soc. Edin., vol. ix., p. 461. Mentions the occurrence of coal in Suderö, Myggenaes, and Tindholm. The paper is illustrated by a section through Suderö, showing the horizon of the coal. Numerous sketches are given showing the appearances of certain columnar basalts in Stromö, &c.

Dr. Forchhammer. "Om Færöernes geognostiske Beskaffenhed." Det kongl danske Vidensk Selsk. Skrifter, 1824. Describes the coal bearing beds of Suderö, &c., and gives a general account of the geology of the islands. Illustrated by a map showing geological features.

Robert Chambers. "Tracings in Iceland and the Færöe Islands." Chambers's Edinburgh Journal, 1855. Refers to marks of glaciation.

C. Wyville Thompson. "The depths of the Sea." Dredging expedition of the "Porcupine" and "Lightning." Macmillan, 1873.

F. Johnstrup. "Om Kullagene paa Færöerne samt Analyser af de i Danmark og de nordiske Bilande forekommende kul." K. D. Vidensk. Selsk. Oversigt, 1873, p. 147. Gives an account of the coal beds of Suderö, and compares the quality of the coal with that of Bornholm, Newcastle, Iceland, Greenland, &c. Numerous analyses of the coal are given, and the paper is accompanied by a coloured map of Suderö and a section across Suderö, showing coal strata.

F. Johnstrup. "Sur les couches carbonifères des îles Færoë et les analyses des charbons du Danemark et des possessions danoises dans le Nord." Rés du Bull. de l'Acad. Roy. Dan. des Scienc et d. Lettr. p., 1873, p. 57.

A. H. Stokes. "Faröe Islands. Notes upon the Coal found in Süderöe." Q. J. G. S., No. 144, 1880, p. 620. Gives full description of the occurrences of coal in Suderö, its method of working, calorific value, analyses, &c., accompanied by a map showing area under which coal is found.

James Geikie. "On the Geology of the Færöe Islands." Trans. Roy. Soc. Edin., vol. xxx., part 1, p. 217. Gives a full and admirable account of the geology of the Islands. The glacial phenomena are particularly well described, and the paper is illustrated by a map and three plates.

Amund Helland. "Om Færoernes Geologi." Dan. Geografisk Tidskrift, 1881. Mr. Helland accompanied Dr. Geikie on his visit to the Islands, and his conclusions are in accord with those given in Dr. Geikie's paper.

Physical Features.

The islands are 26 in number. They mostly have a trend N.W. and S.E., and are separated by long narrow fiords. Most of the islands lie side by side, forming a northern group, which has its greatest extension E. and W. Besides the main fiords which sever the northern group into separate islands, there are other fiords which run far into the land. They have as a rule the same trend as the main fiords. It is a significant fact that nearly every closed fiord running towards the north has a counterpart from the north running south. The two arms sometimes almost meet in the middle line. Thus several of the islands consist of two parts joined together by only low isthmuses. A line drawn from Fuglö in the east to Myggenaes in the west would traverse most of these connecting ridges or saddles. Where soundings are shown on the map, it is seen that the main fiords or straits are shallow where the line crosses and deepens north and south. So far as we could observe there is no structural peculiarity in the rocks themselves which could account for the fact.

It is purely a matter of erosion. The line also marks the principal water parting of the present day.

The interior of the islands is very mountainous. Some mountains, as Slattertind and Skiellenge Fiall, are over 2,000ft. high. Their summits are frequently flat topped, while in other cases they rise to sharp peaks.

The slopes of the mountains usually descend in great steps towards the sea. The cliffs are very steep, and but few places exist where landing is possible.

Often they present a vertical face over 1,000ft., or, as the case of Myling Head, over 2,000ft. in height. In the neighbourhood of Saxen the cliffs have been worn into natural arches and caves.

The final breaking down of these arches can be seen in the many isolated stacks or Drangas which are very common round the shores.

There are not any streams of importance in the islands. They are mostly rapid torrents, having but a short course from the mountains to the fiord or sea. There are a few small lakes, most of which seem to occupy true rock basins.

The largest is Sorvaagsvatn in Vaagö. It is about four miles in length, and a little more than half a mile broad. Although we were at Midtvàag, not more than half a mile distant from the lake, we were prevented from visiting it, as the state of the tide rendered it imperative for us to move on at a certain time.

We, however, saw the Waterfall Busdalifoss, near Trelle Nypen, which is formed by the water which overflows from Sorvaagsvatu.

Near Leinum are several lakes. We passed these on our way from Kollefiord to Leinum. Two small and almost circular lakes occur high up on the Leinum side of the watershed. Another larger one, almost circular, and half a mile in diameter, is found in the valley nearer Leinum. It is surrounded by some of the loftiest mountains in the islands.

A small lake occurs in Osterö, in the low ground North of Eide.

Besides the Busdalifoss, fine waterfalls exist at Westmannhavn and in other places.

Geological Structure.

General Features of the Strata.—Evidence of volcanic activity during Tertiary times is seen along a north and south line extending from Ireland to Iceland, and perhaps to Greenland. The basalts of Antrim, Mull, Skye,

Faröes, and Iceland, represent the products of this activity.

A submarine ridge is known to extend along this line from Britain to Greenland. This may represent a rift or fissure out of which the basalts have flowed.

At certain points the flows may have been concentrated, and from the vents great plateaux of igneous rocks have been built up. One of these vents probably existed near the Faröes, and the islands, as we see them at present, represent the plateaux cut and carved by marine and subaerial agencies into a cluster of islands.

It by no means follows that at all the centres the lava was poured out at the same time. The fires in the northern extremity are not yet extinct, as is shown by Heckla, Oræfajökull, and other active volcanoes in Iceland.

The activity may have died out gradually from south to north.

The occurrence of great fields of bedded basalt does not necessarily carry with it the idea that lofty cones existed from which the materials flowed. The absence of fragmentary materials, such as usually accompany volcanic outbursts, certainly argues against such having existed. It is scarcely probable that all traces of agglomerates and ashes would have been obliterated in the Faröes, seeing that shales and other rocks, equally susceptible to erosion, have escaped.

Old land surfaces, with soil and signs of vegetation, are of frequent occurrence, and these speak of the intervals which elapsed between successive outpourings of the lava, of sufficient length to allow of the disintegration of the surface rock, the formation of soils, and the growth of plants.

The lofty cliffs afford excellent sections for the study of the lava flows.

The beds vary in thickness up to about 100ft. The upper and lower surfaces are, as a rule, amygdaloidal, and in the cavities thus formed the minerals for which the Faröes are so celebrated, are formed. These cavities range up to three and four feet in diameter. Sometimes they are irregular in shape, but frequently they are drawn out in one direction.*

The basalts themselves are frequently columnar, and sometimes show a line of vesicles extending along the middle of the layer. The reason for this is not far to seek. The basalt, on cooling, contracts. The cooling takes place inwards from the upper and lower surfaces, so the liquid interior as it shrinks is not sufficient to fill the space. The dissolved steam then escapes, and forms vesicles.

In some lofty cliffs, as at Trelle Nypen and along the west coast of Stromö, the rocks show great master cracks which extend from top to bottom of the cliffs.

So we have the individual layers with columns proper to themselves, and other, greater, columns of gigantic size, embracing the smaller. It is owing to these master cracks that the cliffs preserve their vertical faces, and do not exhibit steps such as are seen bordering the fiords.

The beds of basalt are very persistent, and individual layers can often be traced for miles without showing much variation. The amygdaloidal portions, however, frequently show curious features, which I do not remember to have seen described.

* On the W. coast of Svinö, about 20ft. above high water mark, there are several remarkable cavities seen in the cliff. In section, one of them is perfectly circular, about 1ft. in diameter, and extends inwards to a distance of at least 6ft. or 8ft. Its appearance is exactly like what is seen in looking into the mouth of a cannon. Whether this is an amygdule or not I could not say.

Laccolites.—In the middle of the amygdaloidal layers patches of compact and highly columnar basalt occur. They are sometimes only a few feet long; at other times they extend for hundreds of yards. The prevailing form is like a plano-convex lens, with a flat base and arched top. The columns are not all parallel to each other, but are arranged normally to the upper surface. Thus they have the appearance of converging towards the central point of the base.

These are well displayed along the south coast of Waagö; a fine example exists near the Witch's Finger, also in Naalsö, in Borovig, Svinö, Fuglö, near Hoyvig, in Myggenaes, and in many other localities.

Sometimes they are almond shaped, and show columns running vertically from the upper to the lower surfaces. In other cases the columns proceed from the upper and lower surfaces, but do not meet in the middle line.

Occasionally forms are seen which bifurcate. The branches may take the form of long strings, but they preserve the same general direction as the main mass, and so far as I could see none were inclined to it at any considerable angle.

They are evidently intrusions into the soft and easily-yielding rock, and are not formed at the expense of the amygdaloidal layer.

This is proved by the fact that the layer preserves the same thickness where an intrusion exists as at the sides. Where a lenticular intrusion occurs the layer breaks into two portions, one part underlying the lens while the other arches over it. The aggregate thickness of the two portions is, however, just the same as the part not broken.

From the persistent easterly dip, and on other grounds, I am inclined to agree with Dr. Geikie that the flow was towards the east, and the actual vent was situated to the west of the islands.

Characters of Basalts.—The basalts vary much in colour and texture. The colour ranges from black to dark brown. The amygdaloidal portion is mostly dark red or brown, but not unfrequently it is greenish, and even blue.

The basalts in the north part of Osterö show a very large proportion of Olivine—in fact some specimens seem to be composed mainly of that mineral in a fresh and glassy condition.

Needles of Plagioclase Felspar—probably Labradorite—are also seen in the microcrystalline ground mass.

A very pretty porphyritic basalt occupies a large tract between Kollefiord and Leinum. The bed of the river which runs into Kollefiord is wholly composed of this rock. In a microcrystalline base which contains Felspar, Augite, and Olivine, are dispersed large white crystals of Labradorite. Some are upwards of an inch in length. They are arranged mostly in a stellate manner.

In the cavities of the amygdaloidal portion many exquisite specimens of zeolites are found. Perhaps the best localities for these are in Svinö and Fuglö. At Svinö we found Chabazite in great abundance. One crystal measured 1⅞ inches long, and many were seen over an inch.

At Fuglö beautiful examples of Analcime were found, in the form of clear transparent trapezohedra. Near Leinum Lake a slab occurred, covered with most exquisite crystals of Stilbite, Chabazite, Heulandite, and other minerals.

Natrolite was found almost everywhere, but the finest examples were obtained near the natural arches, south of Saxen. The cavities here were covered with long radiating tufts of Natrolite; the needles were clear and glassy-looking, and about three inches in length. Curious spheres and hemispheres of radiating Stilbite also occur at this place. Apophyllite was found in abundance in the rocks above Eide (Osterö) as well as in Naalsö.

Near Eide, Opal, Hyalite, and Chalcedony are found, the latter occurring as plates, as linings of cavities, and as stalactites.

In Naalsö, besides fine examples of Chabazite, Stilbite, Natrolite, and Heulandite, beautiful crystals of Calcite occur. They are mostly rhombohedra $\{10\bar{1}1\}$ R, and some specimens have their edges truncated by faces of $\{01\bar{1}2\} -\frac{1}{2}$ R.

I have not yet had the opportunity of working up thoroughly the collection of minerals brought home. They will probably furnish material for another communication in the future.

Dykes and Intrusive Sheets.—These are extremely abundant. Those we saw are noted in the accompanying map, but others are recorded by Geikie in places we did not visit.

The material of the dykes is mostly a fine grained compact basalt. In some of the smaller dykes it approaches a magma basalt, while in the interior of the larger dykes and sills it is fairly coarse.

Mackenzie mentions that some dykes have a vitreous lining. Although we looked very carefully for this, we never succeeded in finding any undoubted case. It would be remarkable if none occurred, as the conditions are very similar to what we find in the Western Isles of Scotland, where basalt glass is very common.*

* See Proc. Liverpool Geo. Soc., 1888-9.

In Fuglö a beautiful dyke is seen near the landing place at Hattervig. It ends in a cave, and can be traced for a considerable distance through the rocks above. It sends off many thin strings into the adjacent rocks. A dyke a little further to the east runs as a vertical band through the brown amygdaloidal basalt. No columns are seen, but signs of fusion are evident at both sides.

South of Fuglö, near Kirke, a fine intrusive sheet is seen. It is about 50 feet thick, and throws off many branches into the adjacent rocks.

On the north coast of Svinö, and just opposite Kirke, a similar sheet is visible, and can be traced in undulating curves along the cliffs for nearly a mile. Several dykes occur in the bay of Svinö, on the west coast of Svinö, and at various places along Borovig.

All along the coasts of Stromö dykes and sills appear. Many of these I only saw from the boat while rowing close to the shore, and so had no opportunity of examining them closely. The natural arches near Saxen exhibit very fine dykes, and probably they largely owe their origin to the removal of dyke stuff.

While rowing through these wonderful caverns we often noticed that columns of dykes formed the roofs. Perhaps the finest intrusive sheet in the islands is the one seen along the shores of Westmannhavn fiord. It can be traced from Negwa, past Dahlnyppe and Skellingefiall to the crest of the hill above Leinum.

Two beautiful sills occur on the north side of Myggenaes. The columns in the upper sheet are about 70 feet in height; those of the lower are a little less.

Another sill occurs at Frodbö, near sea level, and is described by Geikie.

Old Land Surfaces.—Mention has already been made of the layers of earth which frequently alternate with

layers of basalt. They are mostly brick-red in colour, but they sometimes show other colours—grey, black, and green.

It would be impossible to enumerate all the places where these earths are seen.

In all the islands we visited they occur, especially along the south coast of Waagö are they well developed.

At Myggenaes thin bands of red earth are extremely abundant.

On the top of Myggenaes a fine brown-coloured soil occurs. It is in some places 15ft. to 20ft. thick. The particles forming it are extremely minute, and not a trace of large fragments can be found enclosed in the mass. In all probability it has resulted from the chemical decomposition of the basalt *in situ*. Such a deposit, overlaid by a layer of hot basalt, would produce rocks exactly of the nature of the red baked earths.

Where vegetation had gained a foothold we should expect carbonaceous shales, and perhaps coal.

Such shales and bands of coal do occur in Myggenaes. One outcrop is at an altitude of 1,300ft., and is visible on both the east and west sides of the island. The coal is five or six inches thick, resembles anthracite, does not soil the fingers, and breaks with a conchoidal fracture.

An analysis, kindly made for me by Mr. J. H. des Landes, shows only about 4·5 per cent of ash. We found another seam at an altitude of about 50 feet, near the landing place.

Coal is also said to occur in Gaasholm and Tindholm, as isolated patches in the basalt.

The sea was not favourable for landing on these islands, so I had no opportunity of examining the character of the coal there.

The most extensive occurrence of coal and coaly shale is in Suderö.

The beds have been so often described that I need not dwell on them here, except to mention a new horizon which has lately been exposed during excavations made in the construction of a jetty a little west of the present landing place at Trangisvaag.

The section (see Plate, Fig. 1) is about 25 feet high, and shows 10 feet of coaly shale at the base, in which are seen lenticular patches of good coal. It is not so glossy as the Myggenaes coal, contains more ash, and shows markings which are very suspicious of plant structure.

Glacial Phenomena.

Glacial Striæ.—Excellent examples of striæ were found in almost every island we visited, wherever the rock had been recently bared of its covering of turf. Our stay in Suderö was very brief, and the only traverses we made were in the neighbourhood of Trangisvaag and to Frodbö. A platform of rock near the Doctor's House showed most exquisite striæ. Its surface was perfectly planed, and the deep, clear cut striæ pointed down the fiord in a direction of 24° E. of S. (Mag.) All along the hillside between Trangisvaag and Frodbö bosses of rock showed striæ pointing in the same direction.

At Thorshavn they are well seen on the way to the Fort, near the Cemetery, and on the smooth rocks about the landing place.

At Eide (Osterö) striæ exist on the vertical faces of the basalts which bound the low isthmus on each side. Here they point northwards, and indicate that a mass of ice thrust its way through the narrow gorge out to sea.

From observations in other islands it is clear that the movement of the ice accorded with the existing trend of the valleys and fiords.

The E. and W. line before mentioned, drawn from Fuglö to Myggenaes, marks out the places where the iceshed took place for the northern group.

Roches Moutonnées.—Roches moutonnées are met with principally in the valleys and on the slopes of the fiords. Geikie describes and figures the rocks about Westmannhavn, where the surfaces of the lava beds have been smoothed down to one continuous and unbroken curve. Similar features are met with in the Sundenfiord, and along all the inland valleys. Where a band of highly columnar nature is met with, the columns break away as a whole, and assume a craggy aspect. The soft amygdaloidal layers easily yield, and where they alternate with the harder bands, a stepped arrangement is the result. This is very noticeable on the sides of Borovig. The hard compact beds sometimes take on a high polish, and can be traced for long distances by that feature alone. The direction of ice movement, as deduced from the lee and weather sides of the roches moutonnées, corresponds with that indicated by the glacial striæ.

In Sundenfiord, north of Qualvig, the movement is north. South of Qualvig it is south.

The fiord about Qualvig is very shallow, and deepens towards Eide and Naalsö. I am inclined to ascribe this feature to the scooping action of the ice itself. The fiord must have been glutted with ice, and not finding a sufficiently wide outlet past Tiornevig, it would cleave on the peninsula of Kodlen, and part would go across the low ground north of Eide.

Cirques.—The principal valleys run across the strike of the rocks. The structure of the islands being so uniform, we should expect the pre-glacial rivers to carve out valleys in a uniform direction. As practically no

folding or displacement of the beds has taken place, they would tend to flow in narrow deep channels from the watershed towards the sea. Drainage from the high grounds bordering the valleys would give rise to smaller valleys at right angles to the main ones, and these again would receive minor tributaries. The ice, on filling the valleys, would modify their forms, but not change their directions. A river cuts vertically, whereas ice filling a valley rasps the sides as well. Bearing this in mind, we can see how the upper reaches of a valley may become U shaped under the action of ice. The fiords show innumerable side valleys of this nature, sometimes with small lakes nestling in their hollows.

For convenience we may divide the cirques into simple and compound. The former show a main valley into which open tributary valleys, and resemble river systems with the heads of the valleys U shaped instead of V shaped. Simple cirques show only one valley, which opens directly into the sea or fiord. Compound cirques are found almost exclusively in the fiords, while the simple cirques are very characteristic features in coast sections.*

It is probable that many of the simple cirques are the remains of compound ones which have been cut back by the sea past the junctions of the tributaries.

But marine erosion has gone further, and broken up the land into clustering islands, which in many cases still exhibit the outlines of cirques. Tindholm, the Drangars, and other islands south of Sorvaagsfiord may be given as an example (Plate, Fig. 3).

We can reconstruct the form of the cirque surface from their slopes, and that of the adjacent shores of

* For a fuller description of the cirques and their mode of origin see Glacialists' Magazine, June 1895.

Waagö. Kolter, Hestö, Fuglö (Plate, Fig. 4), Svinö, Skuö, and other islands all show that before they became islands they formed parts of lands deeply carved by cirque valleys.

In this way we get a measure of the enormous amount of erosion which has taken place since glacial times.

Curious features are often exhibited by the cliffs when continued inland. Along the S.W. of Waagö, at Myling, and on the east coast of Myggenaes (Plate, Fig. 2), we have lofty and steep cliffs sometimes over 2,000 ft. high; their tops are perfectly sharp, and their slopes inland sweep down in a steep curve. The seaward faces retain their vertical form as they are cut back, so the sharp top will be preserved until the valley of the cirque is exposed to the action of the waves.

Glacial Débris—Moraines.—With the exception of a small area round Thorshavn, no level ground is found in the Faröes. There being no suitable places on which the ice could lay down its *débris*, we could scarcely expect to find real Moraines. The *débris* was probably taken out to sea and deposited there.

Glacial Mounds.—The short steep slope of the ground towards the sea would naturally cause the ice to move very rapidly.

Under the iceshed line, however, there would be very little onward movement, and we might expect that to be a place of deposition.

It is remarkable that on that line occur the only cases of glacial mounds we found in the northern group. In Svinö the low saddle shows beautiful mounds, having their axes N.W. and S.E.

At Klaksvig and Qualvig glacial mounds also occur. At the latter place they are scattered abundantly over the

ground to the east of the village, and in the north part of the bay itself. They consist of stones of varying sizes, piled up in conical mounds. No clay was visible, but a fine sandy material filled the interstices between the larger stones.

Boulder Clay.—Boulder clay of a greyish or reddish colour, stiff and crowded with scratched stones, also occurs, mainly in the line of iceshed at Fuglö, Svinö, and Klaksvig. No shell fragments were found.

At Trangisvaag boulder clay is found capping the section described above where coal is found. (Plate, fig. 1.)

Boulders and Perched Blocks.—Boulders occur in profusion in all the valleys. None are of foreign origin. Perched blocks are often met with on the smooth bosses of rock. Fine examples are seen on the high ground near Hoyvig.

Extent of Glaciation.—The whole islands were undoubtedly subjected to glaciation. The limits of glaciation in Myggenaes we ascertained as being about 1,600 feet above sea level. At other places it was probably lower.

Nunataks would exist in the high grounds. This is proved by the absence of glaciation in the highest peaks, and Col. Fielden has pointed out that the flora of the nunataks is distinct from that of the low grounds.

No raised beaches are met with, and there is no evidence that the land stood at a higher level during the glacial period.

EROSION.

At the present day erosion is taking place at a very rapid rate. Particularly on the west and north coasts the sea beats with great force.

Every circumstance points to the former extension of the land towards the west. There must have been large

ground to the east of the village, and in the north part of the bay itself. They consist of stones of varying sizes, piled up in conical mounds. No clay was visible, but a fine sandy material filled the interstices between the larger stones.

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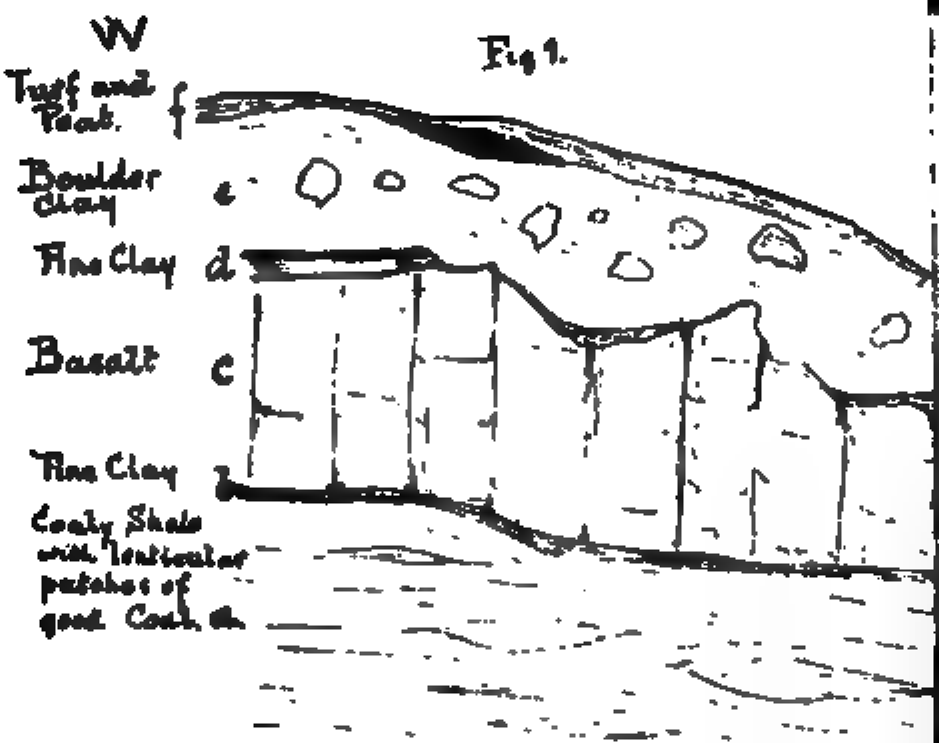
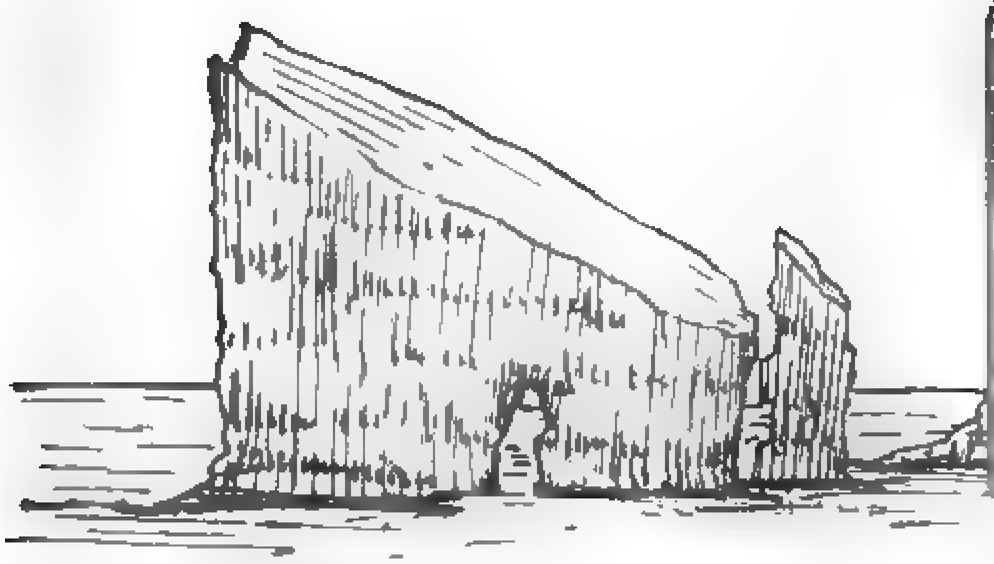
Fig 1.



Section near Trangisvaag.

Fig 3

Drangars.



gathering grounds to supply the ice necessary to fill the cirques existing at Myling, Wangö, and other places on the west coast. The ice undoubtedly came from the west, and now the cliffs themselves form the outer walls of great cirques.

The cliffs as a rule are very precipitous, and descend at once into deep water. Very few places show beaches composed of sand or shingle. The best example is found at Saxen.

The sand is greyish in colour, and might be mistaken for the quartz sand of our own shores. On close examination it is seen to consist wholly of fragments of zeolites and little rolled pieces of basalt, but not a trace of quartz was visible.

Explanation of Plates.

Map of Faröe Islands. The outline and hill shading are based on the Admiralty charts.

Route shown by dotted red lines, and geological features in red.*

PLATE.

Fig. 1:—

Section on shore near Trangisvaag.
- (*a*) Coaly shale with lenticular patches of coal.
- (*b*) Fine clay.
- (*c*) Columnar basalt.
- (*d*) Layer of fine laminated clay which extends into the open joints of the basalt columns.
- (*e*) Boulder clay with scratched stones.
- (*f*) Turf with Peat in hollows.

Fig. 2:—

View from Myggenaes, looking East. In the foreground is seen part of the cirque forming E. part of Myggenaes. In middle distance Gaasholm and Tindholm. In the distance the islands of Waagö and Stromö. The low islands to the right are Sandö and Skuö.

Fig. 3:—

View of Tindholm and the Drangars from the E. The island of Myggenaes is seen to the right of Tindholm.

Fig. 4:—

View of north-east end of Fuglö from the south. Shows part of cirque round Hattervig.

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* Acknowledgment should be made to Capt. A. R. Dwerryhouse for the care he has bestowed in the preparation of the map.

FURTHER NOTES ON THE SECTION AT SKILLAW CLOUGH, NEAR PARBOLD.

By E. Dickson, F.G.S.

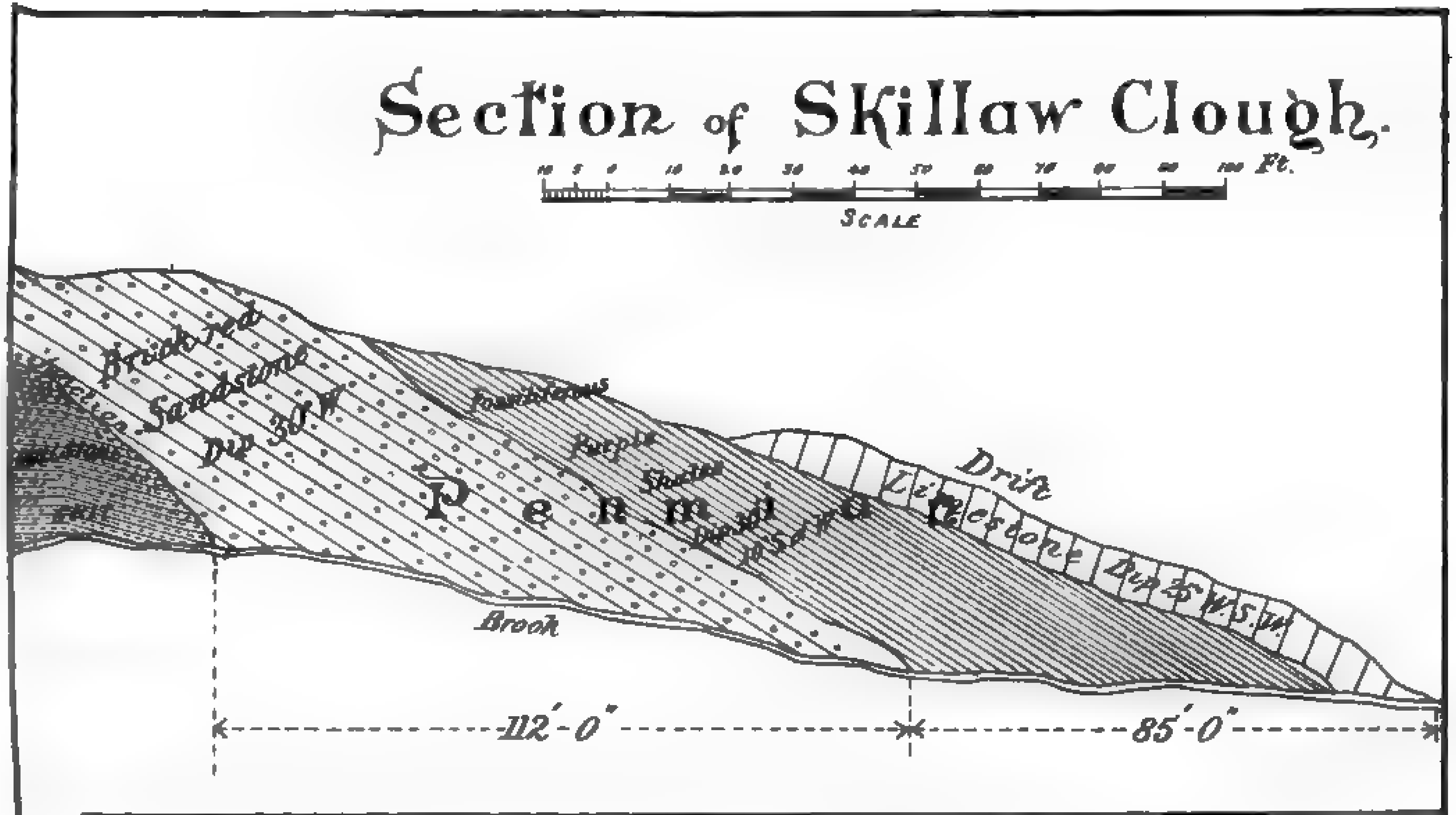
(*Read 12th March, 1895*).

In a short note read before this Society in the Session 1892-93,* I mentioned very briefly the leading characteristics of this very interesting and instructive section. Since that time I have more carefully examined it, in company with Mr. J. Leese, Jr., M.A., F.G.S., who has, since my communication was read to the Society, published an interesting and valuable account of the section in the Second Report of the Southport Society of Natural Science for 1891-3. In this paper Mr. Leese gives three reasons why this section and the exposure at Bentley Brook should interest geologists: (1.) As it includes a true magnesian limestone resembling some of the magnesian limestones of the North Eastern Counties; (2.) As the Permian occurs in direct contact with the Millstone Grit; (3.) As it is the most westerly exposure of the Permian Outcrop surrounding the Lancashire Coal Field.

The dell lies about 300 yards south of the road passing Bispham Hall in the direction of Newburgh, and is about two miles from Hoscar Moss Station. The dell is somewhat obscured by drift and rank vegetation, and the sides are more or less covered with wash from the shales. A small stream runs along the dell, cutting its way through the soft red sandstone.

The total length of the section, measuring from the point where the limestone bed comes down to the stream to the junction with the purple grits of the Millstone

* Proceed. Liverpool Geo. Soc., vol. vii., p. 106.



L'POOL GEOL. SOCY VOL VII PL 3

TO ILLUSTRATE MR DICKSON'S PAPER

Grit, is about 200 feet. The succession of rocks met with in the section, in a descending order, are—

(1.) Magnesian Limestone, 5—6 feet.

(2.) Red Purple Marls and Shales, 30 feet.

(3.) Soft Red and Brown Sandstones, 35 feet.

(4.) Grey and Purple Shales and Grits (Millstone Grit).

The limestone bed, which from its greater hardness has protected the underlying shale, has a dip of 25°, 10° north of west. The rock itself is a hard grey limestone, weathering to a yellow colour, and effervesces freely in dilute HCl. The occurrence of a magnesian limestone is a most unusual feature in this part of England. It differs in composition from the Permian limestones which skirt the South Lancashire coal fields, in that the latter contain only a little magnesian carbonate, whereas the Skillaw Clough limestone contains 24·15 of this base.* In the opinion of the late Mr. Binney the Skillaw Clough limestone strongly resembles the magnesian limestone of Stank, Barrow Mouth, and other places in North Lancashire, of which it might originally have formed a part.† I forwarded a specimen of the limestone to Mr. Hobson, M.Sc., F.G.S., of Owens College, Manchester, and asked him to compare it with any specimens from the district there might be in the Owens College Museum. He has kindly done so, and says, with regard to the specimen: "On comparing it with the few specimens from this "district there are in the Museum, it does not appear "to resemble them. They are mostly red and marly, "and the specimen from Skillaw Clough is much "more like typical magnesian limestone." I am also very much indebted to Mr. Hobson for examining a

* See analysis given in previous paper.

† Survey Memoir, Country around Wigan.

slide of the limestone and writing the valuable note upon it appended to this paper. Mr. Watts, of the Geological Survey, kindly compared a fragment of the Skillaw Limestone with specimens of Permian Limestone at the Jermyn Street Museum, and states that the Skillaw Limestone looks rather like a specimen from Hilton Beck, Westmoreland, and is more earthy and less crystalline than the specimens from the North-Eastern Counties. The limestone contains small patches of calcite, and, as mentioned in the Survey Memoir before referred to, small curved veins of the same mineral, which Professor Hull there states to have been probably formed in the cavities once occupied by fossil shells. Whilst examining the limestone with Mr. Leese I was fortunate to find in it a trace of a fossil, which Mr. Bolton, of the Owens College Museum, has determined to be the cross section of a *Schizodus Schlotheimi*, the first fossil found in this limestone. Fossils are certainly not plentiful in it, and this is the only one I have yet succeeded in finding. The rock is very hard and difficult to break, but I have no doubt that further investigation will lead to the discovery of further fossils. The rock is a genuine magnesian limestone, as a reference to the analysis given in my former note* will show. The proportion of carbonate of iron (9·15) which it contains is certainly remarkable, and largely exceeds the general average found in magnesian rocks. Wishing to examine the insoluble residue of the limestone, I took a fragment weighing 7·5 grammes, and dissolved it uncrushed in dilute HCl. The residue was washed on a filter and dried. The amount of insoluble residue produced showed the presence of a comparatively large proportion of insoluble matter in the limestone. Looked

* Proceed. Liverpool Geol. Soc., vol. vii., p. 106.

at with a lens it is seen to consist of silica, pyrites, and carbonaceous matter. Mr. Rutley, to whom this insoluble matter was submitted, has kindly made the following note upon it:—"In the insoluble residue (after "treating with HCl), there are exceedingly minute double "refracting particles, from which no definite interference "figures can be procured. In the case of one of the larger "grains the arms of a cross were visible, but ill-defined, "their intersection lying outside the field. They were "those of a uniaxial figure, and appeared positive, but "upon this point I could not be quite certain. I am "inclined to think that the doubly refracting portion of "the insoluble residue is quartz, while the opaque portion "consists, at all events in part, of pyrites. The opaque "specks in the section are all seen in reflected light to be "pyrites." Many of you are, no doubt, acquainted with the researches of Mr. Wethered on the insoluble residues obtained by acid treatment of the carboniferous limestones.* In specimens of the carboniferous limestone series at Clifton he found the percentages of insoluble siliceous residues to vary in the several beds of that series from 1·1 to 81·6 per cent. The latter figure was, however, quite exceptional, the average amount being under 10 per cent. Mr. Wethered found the residues from these limestones to consist mainly of detrital quartz with amorphous and chalcedonic silica, some of which took the form of casts and pseudomorphs of organisms. In some cases complete crystals were observed with a quartz grain as a nucleus. Fragments of zircon, tourmaline, and pyrites were frequently met with, and from some beds the residues were little else than micro crystals of quartz. The silica occurred mainly in the form of detrital quartz, and also in the three forms,

* Q.J.G.S., vol. xliv., p. 186; vol. xlvii., p. 550; vol. xlviii., p. 377.

amorphous, chalcedonic, and crystalline, the last three varieties being frequently observable in the residue from the same fragment.

Underlying the limestone occur beds of purple shales and marls, having a total thickness of about thirty feet. They consist of soft shales, with bands of harder shales and thin bands or beds of limestone. In the bands of the harder shales Mr. Leese and myself have found a large number of fossils, all of an unmistakably Permian type, proving that these rocks truly are of Permian age. In his paper Mr. Leese refers to three fossiliferous bands in these marls, one a seam of limestone just below the main limestone, from which were obtained fossils identified by Mr. Bolton as *Schizodus obscurus* and *Gervillia antiqua*. a second zone of purple shales about five feet below the limestone containing abundance of *Pleurophorus costatus* and *Gervillia antiqua*, and a third zone of brown calcareous nodules containing abundant casts of *Schizodus rotundatus*, *Gervillia antiqua*, *Pleurophorus costatus*, and *Mytilus squamosus*. The fossils, although by far the most abundant in the above zones and one or two minor zones, are not confined exclusively to them. I have also obtained a large number of fossils from these marls which have not yet been named, but they are, as a rule, only casts, and in a poor state of preservation. The dip of the shales is 30°, 10° south of west. These shales, as they approach the underlying sandstones, assume a darker colour, becoming a dull purple, but I think this change of colour is due in great measure to the action of weathering, as shales which contain ferrous iron would become peroxidised on exposure.

Underlying these shales are beds of soft dark red sandstone through which the stream has also cut its

way. The sandstone is of a deep red colour, especially at the surface, and very soft for some distance below the shales, but gets harder as it approaches the Millstone Grit. At the top of the sandstone and beneath the shale is a bed rich in pyrites. A microscopic examination of the grains of the sandstone shows them to be comparatively large and remarkably well rounded, though, as Mr. Leese points out, in the higher beds the grains are smaller and angular; the lowest bed contains quartz pebbles and fragments of carboniferous shale. No fossils have yet been found in these sandstones.

It is not easy to fix the exact place of junction of the Permian sandstone and Millstone Grit, but after some considerable trouble Mr. Leese and myself have been able to fix and trace the junction of the two rocks in the stream and up the left side of the dell. The junction by careful examination can be seen in a little pool in the bed of the stream, about four or five yards south of where the stream makes a sudden fall, and also, after a little digging, in one or two places on the sides of the dell. The dip of the Millstone Grit near the junction is not easy to ascertain. Mr. Leese puts it as 5°–6° S. near the junction. Mr. Leese in his paper inclines to the opinion that the junction is an undisturbed unconformable one rather than a fault, on the following evidence:—

(i.) That the dip of the junction plane appears to coincide with that of the Permian sandstone in contact with it, 30° Magnetic west.

(ii.) That the sandstone above and the shales of the Millstone Grit below show no signs of crushing, &c., nor is there any trace of fault stuff.

(iii.) That the line of junction when traced up the left slope of the clough makes an outcrop which cor-

responds with the idea of an undisturbed junction rather than a fault.

(iv.) That the basement bed of the Permian sandstone contains water-worn quartz pebbles and water-worn fragments of purple shale resembling the shale of the Millstone Grit.

I am not satisfied that the evidence is so clearly in favour of an unconformity rather than a fault, as apparently it is in Mr. Leese's opinion. The point is one which is difficult of determination, partly on account of the manner in which the strata are obscured by drift and *débris*, and for the present I would prefer to keep an open mind on the subject.

The section is certainly a most interesting one, and will well repay the geologist the trouble of a visit.

NOTES ON A SPECIMEN OF PERMIAN LIMESTONE FROM SKILLAW CLOUGH.

By Bernard Hobson, M.Sc., F.G.S.

The microscopic section shows the great bulk of the rock to consist of well-defined idiomorphic crystals of the ferriferous variety of the mineral dolomite, known as brown spar. The maximum diameter of crystal observed was ·14 m/m., = $\frac{1}{181}$ inch. The crystals show the characteristic rhombic form [probably the rhombohedron face (10$\bar{1}$1)]. They appear to be dirty brownish in colour, owing, no doubt, to the presence of iron oxide. The crystals of dolomite are embedded in a scanty colourless matrix which is most probably calcite, and only rarely shows twinning. This matrix is only distinctly visible in small patches and narrow bands here and there, and

does not apparently constitute a twentieth part of the rock. A few irregular grains of quartz (probably sand grains) occur at intervals. Grains and crystals of pyrites are scattered throughout the section. No determinable traces of fossils were observed.

Turning now to Mr. E. Dickson's analysis given below (I.), I have placed beside it for comparison (II.), that of the Magnesian Limestone of Roker, Durham *—

	I.	II.
Carb. Lime	57·10	59·81
Silica	3·23	—
Carb. Magnesia ..	24·15	26·06
Carb. Iron	9·15	—
Peroxide of Iron. Alumina, Insol. in HCl.	—	14·13
	93·63	100·00

It should be mentioned that the amount of magnesian carbonate in the Magnesian Limestone of Durham varies in different places from 0 to 40 per cent. †

Prof. Zirkel in his "Lehrbuch der Petrographie," second edition (1894) vol. iii., p. 490, advocates the view that the mineral dolomite is constant in chemical composition, and consists of one molecule of calcium carbonate and one of magnesium carbonate, or $CaCO_3$ 54·23°/$_o$ $MgCO_3$ 45·77°/$_o$.

He says that, if this view be accepted, then those magnesian limestones in which the percentage of calcium carbonate exceeds 54·23 may be held to consist of a mixture of individual crystals of calcite and dolomite.

* Browell and Kirkby on "The Magnesian Limestone of Durham." Nat. Hist. Trans. of Northumberland and Durham, vol. i. part 2, cited by me from Mr. E. J. Garwood's article. "Origin of the Concretions in the Magnesian Limestone." Geol. Mag., 1891, p. 436.

† G. A. Lebour, "Outlines of the Geology of Northumberland and Durham," 2nd ed., 1886, p. 32. Lebour says: See Browell and Kirkby's Analyses in the Trans. Tyneside Naturalists' Field Club (no date or volume mentioned).

If we examine the two analyses given above, and take only the two carbonates into consideration, we have—

		I.		II.
Carb. Lime ..	..	70·28	..	69·70
Carb. Magnesia	..	29·72	..	30·30
		100·00		100·00

If we take Prof. Zirkel's view, we should have in the analysis No. I., as first given—

			I.
Carb. Lime, as Calcite	.. ..	..	28·49
Pure Dolomite	$\left\{ \begin{array}{l} CaCO_3 \ 28{\cdot}61 \\ MgCO_3 \ 24{\cdot}15 \end{array} \right\}$	..	52·76

and obviously a very similar result in analysis II. Now the microscopical structure of the Skillaw Clough rock (I.) quite negatives this view, as the calcite matrix does not approach 28·49°/₀ It is curious that the analyses I. and II. both show almost exactly two molecules of carbonate of lime to one of magnesia. Three analyses of the mineral dolomite from Gurhof, Hall and Taberg respectively (quoted by Dana* from Klaproth's Beiträge, 1807-15) show the same ratio. In the case of the Skillaw Clough rock this can, however, hardly be more than a coincidence, as we have 9·15 °/₀ of ferrous carbonate to account for. Hence the examination of this rock favours the view that the mineral dolomite may vary in composition, and is probably an isomorphous mixture of calcium and magnesium carbonates, with, in this case, some carbonate of iron.

* "System of Mineralogy," 5th ed., 1883, p. 683.

Fig 1.

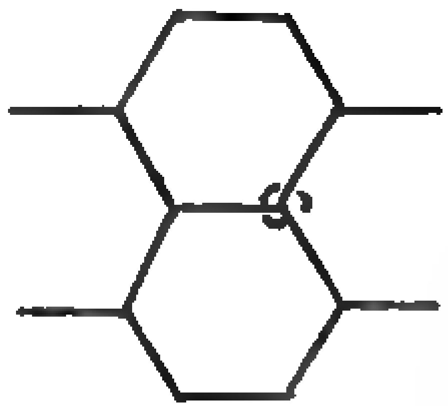


Fig 3

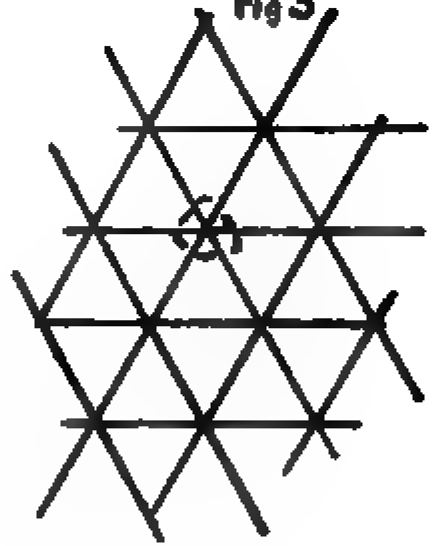


Fig 2

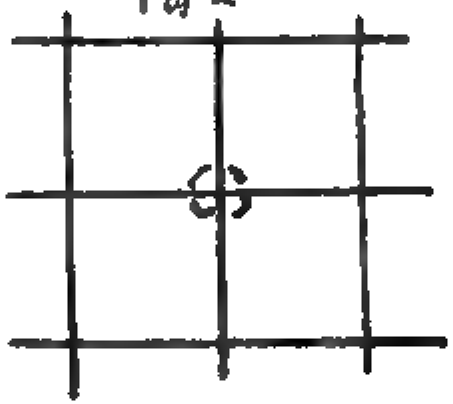
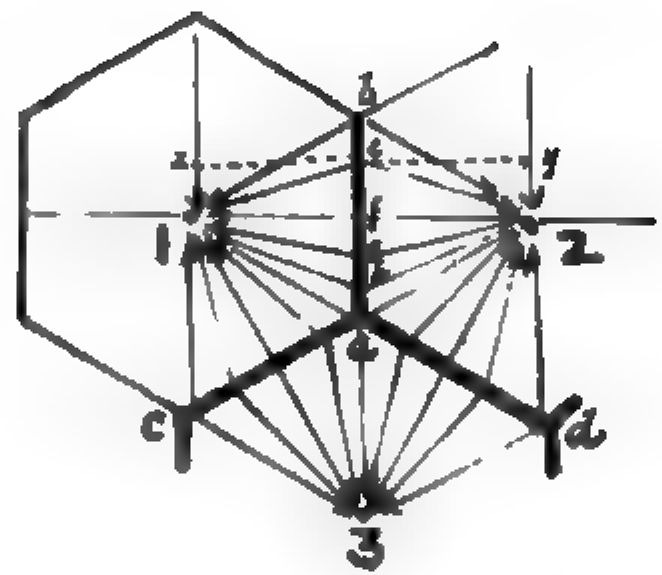


Fig 4.



Proc. Livl. Geol. Socy., to Illustrate Mr. Lomas' Paper.

Pt. 3, Vol. VII.

A THEORY TO ACCOUNT FOR THE HEXAGONAL FORM OF BASALT COLUMNS AND OTHER STRUCTURES.

By J. Lomas, A.R.C.S.

(*Read 12th March, 1895*).

The tendency for rocks of a certain class to break up into columns has long been known to geologists. It is generally conceded that the normal form which the columns assume is a hexagonal prism. Variations from that are regarded as due to accidental causes. The structure is well shown in basalt, basalt glass, obsidian, phonolite, baked earth, mud, peat, in baked sandstone, bricks, starch, &c.

By some people it has been regarded as due to crystallization. It, however, does not exhibit the symmetry and constancy of angle so characteristic of crystals.

Gregory Watt,* after studying the features assumed by molten Rowley Rag on cooling, conceived the idea that it was due to the mutual pressure of spheroids. Du Noyer † shows that this is geometrically incorrect, and would result in the formation of rhombic dodecahedra.

At the present time geologists regard it as a result of shrinkage through loss of heat, or through loss of moisture, as in the cracking of peat and mud.

The present paper does not pretend to discuss the whole question of columnar structure, but is an attempt to explain, on simple mechanical principles, the reason why columns normally take the hexagonal form.

The explanation usually given is somewhat on the following lines. There are only three regular figures which can exactly cover a surface, viz., hexagon, square, and equilateral triangle. To produce the hexagon three

* Phil. Trans., 1804.

† The Geologist, vol. iii., 1860.

cracks inclined at 120° to each other must proceed from one point. In the case of a square four at right angles are necessary, while for equilateral triangles six cracks inclined to each other at 60° must originate from certain points. The subject is not usually followed up further, except to remark that Nature takes the easiest way to do anything, and that three cracks are more easily made than four or six, and hence the columns are hexagonal. [Plate, Figs. 1, 2, and 3.]

In order to avoid repetition, we will confine our examination to the columns as developed in basalt as dykes or sills.

The columns are generally arranged transversely to the length of the intrusion, *i.e.*, at right angles to the surfaces of cooling. Their diameters vary usually with the coarseness of texture of the basalt. Even in the same dyke the columns are smaller at the sides than in the middle. The degree of brittleness also is a factor in determining the size of the columns. Coarse basalt may give rise to columns many yards wide, while in obsidian they can be found almost as fine as needles.

Given a mass of heated rock, homogeneous or nearly so, its width very great as compared with its thickness, and we have the conditions necessary for the production of columnar structure. On cooling, shrinkage takes place, and the rock breaks in the direction in which the tensile strength is least, *i.e.*, transversely. The dyke or sill may or may not break away from the adjacent country, leaving a narrow space between, but the contraction horizontally cannot thus be provided for.

A condition of strain will be set up, and finally the mass will give way.

If homogeneous, the strain will be felt in all parts, and will increase as the matter cools, till the tensile resistance is overcome.

If not free to contract as a whole, differential contraction will take place towards centres situated equi-distant from each other—*i.e.*, the centres will form a network of equilateral triangles.

From the various centres of contraction attractive forces may be said to arise, which might be represented by an infinite number of straight lines converging towards the centre. Adjacent centres would have similar systems. On the confines of the various systems would be situated particles which would be pulled in opposite directions, hence we should expect fractures to occur there.

Take three centres, 1, 2, 3, and let lines 1*b*, 1*e*, 1*f*, 1*g*, 1*h*, and 1*a*; 2*b*, 2*e*, &c., 3*a*, 3*d*, 3*c*, &c., represent forces acting towards the various centres. [Plate, Fig. 4.]

A particle at *f* would be pulled towards 1 and 2. The forces 1*e*, 2*e* can be resolved into components *ex*, *ef*, and *ey*, *ef*.

Similarly all the forces meeting along *ab* can be resolved into forces parallel to 1*f* and 2*f*, and others acting along *bf* and *af*. The latter, being equal and opposite, would balance, and we have left a set of forces acting at right angles to *ab*, and towards 1 and towards 2. Thus a fracture would result along *ab*. It can be shown, by a similar course of reasoning, that cracks would form along *ad* and *ac*. Thus from *a* three cracks would arise, subtending with each other an angle of 120°.

From *b*, *c*, and *d* other triradiate cracks would form, and the resulting figures would be regular hexagons.

NOTE OF FURTHER GLACIAL STRIÆ AT THE QUARRY, LITTLE CROSBY.

By T. Mellard Reade, F.G.S.

(*Read April 9th, 1895*).

In 1876 I recorded some "Glacial Striations at Little Crosby,"* pointing 22° W. of North. Just lately I have observed others on the surface of the Keuper Sandstone about 150 yards south of those previously recorded. A small portion of the "cover," consisting of sand and soil about two feet thick, has been removed on the west side of the quarry, and on the hard surface of the Keuper Sandstone striæ are to be seen. The direction of the most definite of these striations is 30° West of North, and at another spot, five yards south of this, in sweeping off the loose sand from a projecting shelf, another scored line was seen having exactly the same direction.

There must have been much striated rock removed from this extensive quarry since it was first opened, but unfortunately, there appear to have been no observers handy, and the information has been lost.†

The surface of the rock is dead level in the direction of striæ, and dips 1½° at right angles to striæ towards the west. There are short subordinate cross striæ, having a direction north and south, and others less definite cross the main striæ in a direction 15° E. of N. I found in the covering sand a small boulder of Eskdale granite.

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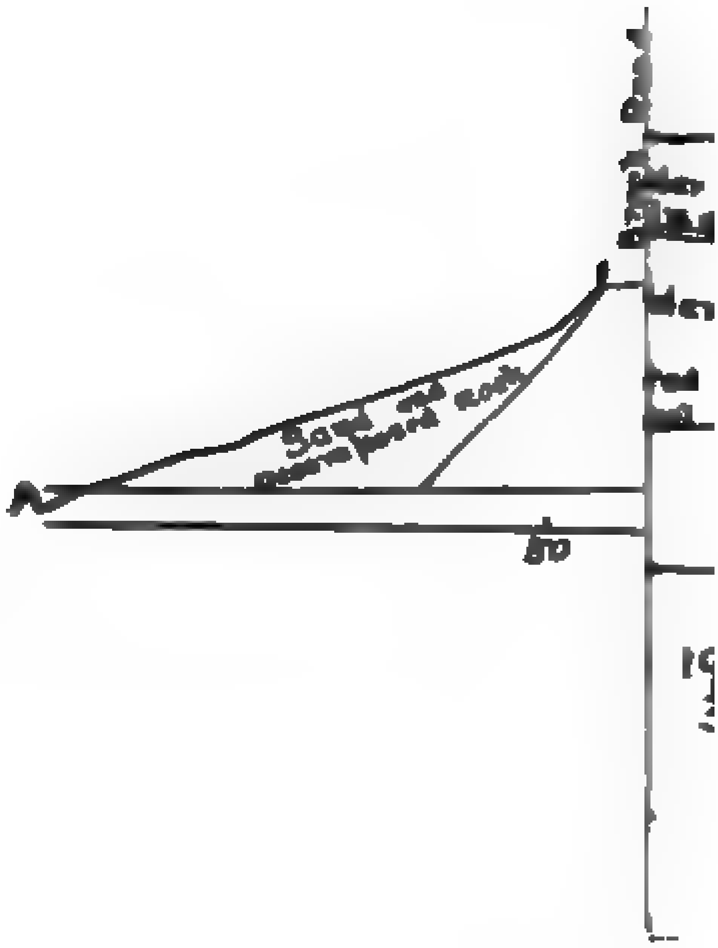
* Proc. of L'pool Geo. Soc., vol. iii., pp. 241-3.

† On the base of the cross in Little Crosby village are to be seen excellent examples of striated sandstone from this quarry, the surface having rubbed so true that it has been left undressed in its natural state. These striæ are not all parallel, some of the striæ crossing the others at a rather acute angle.

Plate I



DESCRIPTION OF THE STRATA EXPOSED DURING THE CONSTRUCTION OF THE SEACOMBE BRANCH OF THE WIRRAL RAILWAY.

By T. W. Davies, A.M.I.C.E., and
T. Mellard Reade, F.G.S., A.M.I.C.E., F.R.I.B.A.

(Read 9th April, 1895).

Introduction.

The Seacombe Branch of the Wirral Railway is about 2½ miles long, extending from Bidston Marsh to Seacombe Ferry.

It is shown on the $\frac{1}{2500}$ Ordnance Map we exhibit, from which it will be seen that it is in the basin of Wallasey Pool. The highest level of the rails is 50 feet above O.D., and the lowest 20 feet above O.D. The greatest depth of the cutting is at Poulton, where it passes through the Triassic rock to be described hereafter more in detail. The Low-level Marine Boulder Clay of the Lancashire and Cheshire plains overlies the rock to the eastward, as shown in the section; and from where the rock dies out under the railway the cuttings to Seacombe are all in the Boulder Clay, with the exception of a small exposure of the Pebble Beds in the Seacombe cutting. (See figs. 1 & 2, Plate 1.)

The Trias.

Commencing at the western end of the Poulton cutting, the lowest strata exposed are the upper beds of the Bunter and the base of the Keuper. The Bunter is for the most part extremely soft, so much so that it can be crushed between the thumb and finger, but in some places it hardens considerably. These hard places occur in patches without any apparent order. Throughout, the rock is full of joints and backs.

The Bunter has evidently been more or less denuded before the Keuper was laid down. The whole of the upper surface of the Bunter lies in irregular hollows, which the Keuper does not follow conformably, but rather fills up the hollows, as shown in the section.

The upper portion of the Bunter contained thin inconstant beds of black oxide of manganese: these were found immediately below the base of the Keuper, and did not extend more than about 12 inches into the Bunter.

Traces of black oxide of manganese were also found at Mill Lane, about five feet below the surface of the road.

The Keuper dips nearly S.E., the dip of the general surface of the Bunter is a little north of east, so that the unconformity of the Keuper with the denuded surface of the Bunter is greater than shewn in the section which follows the course of the railway.

During the progress of the excavation the hard bed of the Keuper immediately overlying the Bunter was removed in large blocks having a superficial area of about 20 feet. The bottom beds of these blocks would be casts of the original surface of the Bunter, and from the appearance of these the surface of the Bunter must have presented an uneven, hummocky appearance, such as is caused by the action of wind and weather on soft rock.

The upper bed was of a whitish colour, which Dr. Ricketts suggests may have been caused by the bleaching effects of the atmosphere before the Keuper was laid down. This whitened rock was considerably harder than the other part of the Bunter Sandstone.

Between the Keuper and the Bunter, for the whole length of the section exposed, there was a thin uneven bed of very soft wet clay, varying in thickness from $\frac{1}{4}$ in. *to 2 in.* This clay is probably an infiltration from the

Boulder Clay above—in fact its course downwards could be traced in several places.

This open bed would point to a movement of the Keuper on the Bunter, probably similar to that which will further on be shown to have taken place in the beds of the Keuper some 20 feet higher up.

The lowest bed of the Keuper consists of an extremely hard coarse brown sandstone, with an uniform dip of 1 in 15 to the south-east. At the west end of the cutting this is a true bedded sandstone about 2 feet thick, but gradually increases to about 6 feet, and changes into a coarse false-bedded pebbly conglomerate.

Going eastwards the true dip remains the same, but the rock is very false bedded, continually changing from a coarse conglomerate into a fine, soft, thin bedded sandstone, and again into a fine, hard, compact building stone.

About 40 yards westward of Mill Lane and 7 feet above the base of the Keuper there was a bed of marl about 20 yards by 15 yards, about 3 inches thick in the thickest place. From the rock above we obtained some casts of suncracks, but, although carefully examined, no footprints were found.

Relative to the subject of suncracks, we should like to state the result of a few actual observations on the behaviour of clay subjected to the drying action of the sun and afterwards exposed to water.

Clay deposited in the bottom of the cutting in the form of mud, by the drainage from the drift on to a damp and impervious surface, took about two weeks of hot summer sun to thoroughly crack into a mesh-work and curl up. When water again accumulated on the clay the immediate result was the flattening out and removal of the twists of the clay flakes; the cracks then

gradually closed, by the swelling of the clay, until in about three weeks they were quite closed up. A thin layer of clay of about ¼ inch, deposited on the Bunter Sandstone, cracked and curled up in a few hours.

It would thus seem that, if the suncracked beds in the Keuper represent similar conditions, they must have been covered by drifting sand while the flakes were curled up, because if they had been covered by water they would have been flattened out before the sand could have got under the curled surfaces in sufficient quantities to have preserved the twist. Also it would seem that the deep cracks in the thicker beds of marl must have been exposed, either to a very hot sun, or have remained exposed a long time if at the temperature of our present summers.

The Slickensides, which have been previously described by Mr. Beasley* in the Poulton Quarry, were found to extend to within about 60 yards of Mill Lane, running nearly east and west.

Near the surface of the rock (Keuper) on the east of Mill Lane, several good specimens of ripple-marked beds were found.

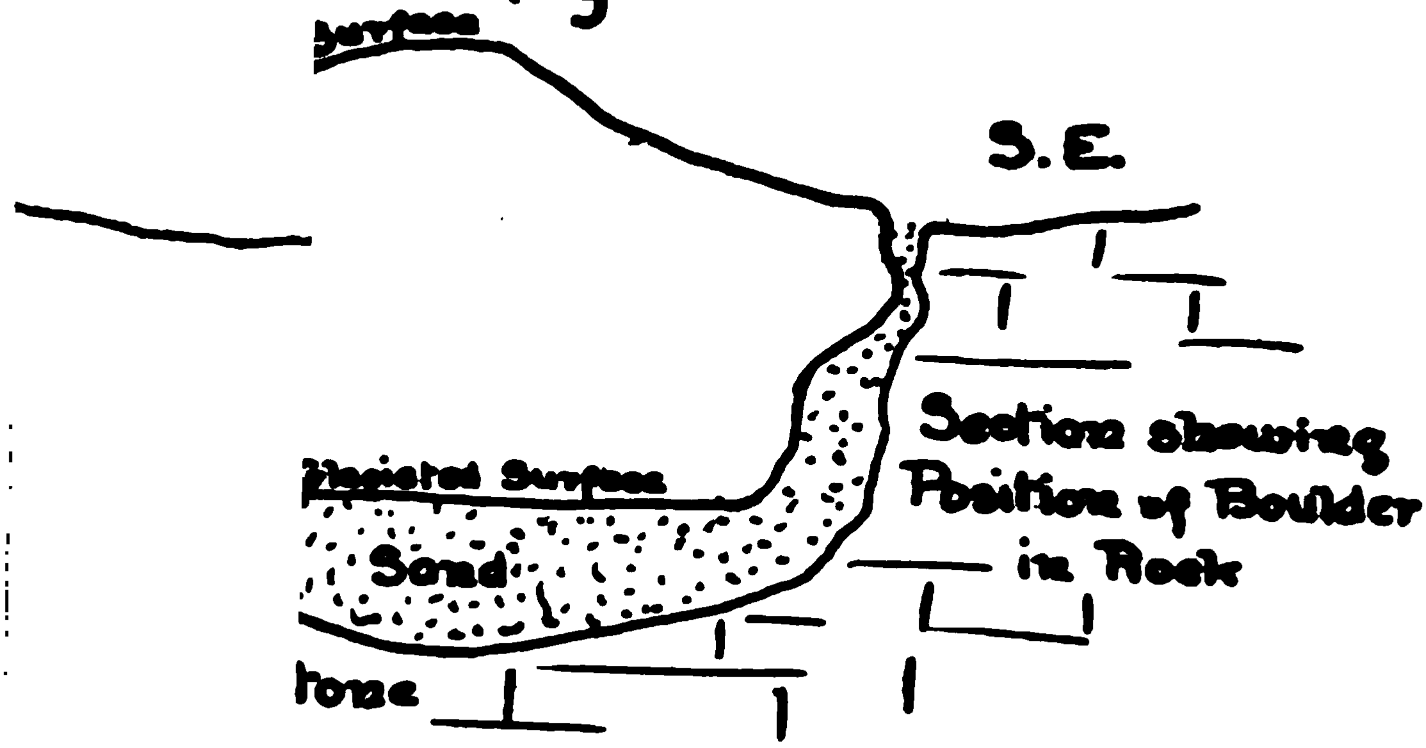
The rock here was observed to be red on the surface, but the red colour did not extend more than from 6 inches to 12 inches into the rock. The colouring matter was clearly derived from the Boulder Clay above.

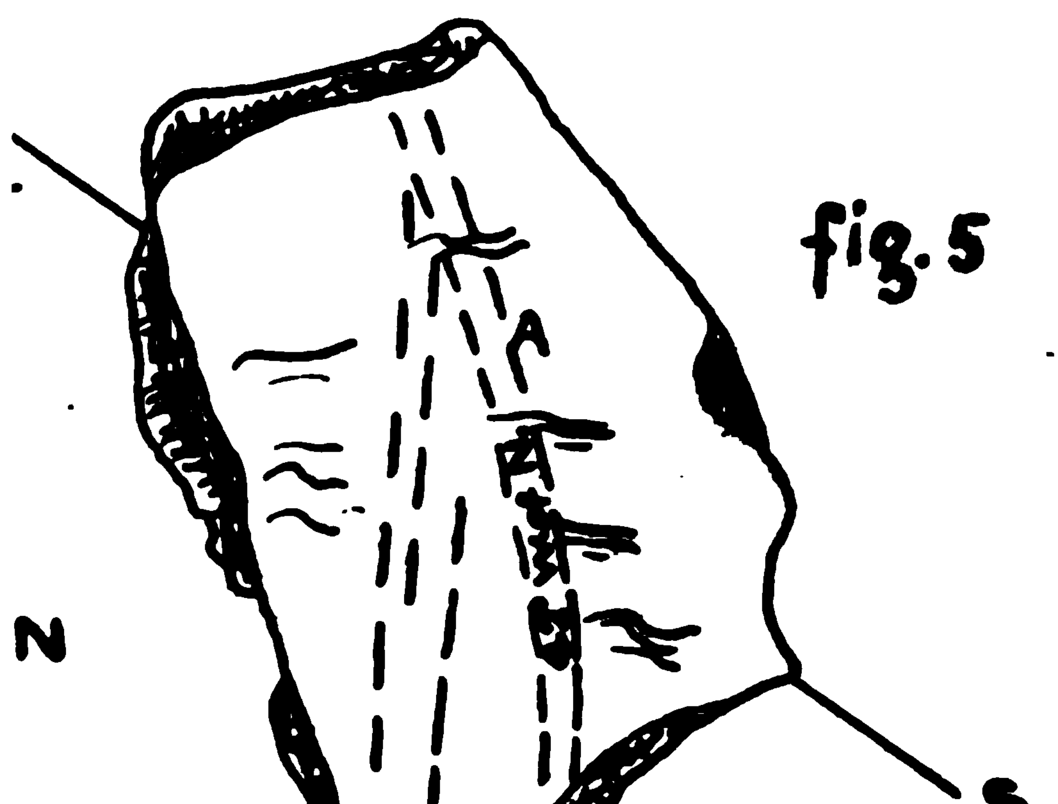
Glacial Phenomena.

From excavations made on the north side of the cutting, between Mill Lane and Breck Road, we find that the Boulder Clay is there much deeper than on the railway, the rock surface below the clay probably forming a narrow ridge falling rapidly away on the south towards

* "A Quarry at Poulton," &c. Proc. of L'pool Geo. Soc., vol. v., p. 85.

fig. 6





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the Wallasey Pool, so that the whole top rock would offer little resistance to a mass of ice travelling from the north.

The whole of the upper beds of the rock have apparently been pushed forward in a south-easterly direction. This movement can be traced from about 200 yards on the west side of Mill Lane, and ends in a mass of crumbled rock about 150 yards on the east of Mill Lane.

The movement is very clearly exhibited in the south side of the cutting to the east of Mill Lane, as represented in the diagram, fig. 1, Plate 2.

During the excavation of the cutting this movement was also clearly traceable by a series of wave-like hollows between two of the beds. Originally one bed fitted into the other, but the upper beds being pushed forward, cavities at A.B. A′.B′. fig. 1, Plate 2, have been left.

The points A.A′.A″. have been pushed on to B.B′.B″., the movement being about 10 inches in an easterly direction. Again the same movement is shown by the breaks in the joints of the rock, c c′, and the hollows d d′ d″.

There was also a movement to the south, as was shown by two joints, which extended across the cutting. This is shewn in plan in fig. 2, Plate 2, the dotted lines representing the upper bed that has been pushed forward. This movement was also about 10 inches, so that the actual direction of the movement would be S.E., and the amount about 16 inches.

The movement has not been regular, but decreases towards the west, and seems to have commenced at a point about 200 yards west of Mill Lane. The total surface moved would be about 350 yards, by a width which we have no means of accurately measuring, but would probably be at least 150 yards.

The upper surface of the rock, where hard, was generally found planed and striated. The striations on the west side of Mill Lane, which Mr. Davies had the pleasure of showing several members of the Society in January, 1894, were especially interesting, being broken up by small faults, evidently dislocations of later date than these striations.*

At the time the cause of these curious phenomena was anything but obvious, but now it is seen to be due to this general movement of the rock. The striated surface is specially interesting, as showing that the movement in the rock took place *after* the striæ were formed.†

Immediately to the east of Mill Lane a small piece of striated rock surface was met with, the bearing of the striæ corresponding with those on the west side of the road.

Going on towards Cinder Lane the rock surface was disturbed and crushed, and no striæ were found until a point 300 yards east of Mill Lane was reached, near to where the rock finally dips beneath the bottom of the railway cutting. Here a very remarkable groove was found; the bearing of this was taken very accurately with a theodolite and found to be 31° west of north, dipping 1 in 42 to the S.E. It was perfectly straight from end to end, but had a curious break in it about 2 ft. 6 in. in extent. This break or absence of the groove was apparently caused by the pebble (?) which formed

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* Similar faultings since glaciation are described by Mr. H. Beasley, in his paper on the Poulton Quarry, Proc. of L'pool Geol. Soc., vol v., p. 87, 1885.

† Dr. G. F. Matthew describes small faults observed by him over a considerable area in the ledges of slate near St. John, New Brunswick. The relation of the faults to the glacial striæ indicates that they are Post-Glacial. The displacements are mostly between half an inch and ten inches.—Bull. xii. of the Nat. Hist. Society of New Brunswick, p. 34.

the groove being tilted out by a hard place in the rock. It is most remarkable that, after travelling the distance of 2 ft. 6 in., it should have returned to the same line. The length of the groove that was visible through the removal of the clay was 48 feet; but, as it disappeared under the clay at each side of the cutting, it is probable that the real length was much greater. (See Sketch Plan, fig. 3, Plate 2.)

The groove is shown in section, fig. 4, Plate 2.

Above this striated surface and lying directly on the rock was a bed of indurated gravel, composed for the most part of rounded stones, and overlying the gravel finely laminated clays and sand, gradually changing into the stiff clay known locally as the "bottom clay."

Near the most elevated portion of the rock at Poulton, after clearing off the Boulder Clay, a boulder of Silurian Grit was found, apparently half embedded in the rock. This boulder was extracted with considerable difficulty, by the aid of two navvies with levers. Before disturbing it we took the direction of the striæ on the top of the boulder, which was N. 35° W., but the striæ at the sides curved round the boulder. (See figs. 5, 6, 7, Plate 2.) The boulder was found to lie in a hole in the Keuper Sandstone, the rock immediately under being crushed into sand. On turning the boulder over, we found that the bottom was a smooth plane, having indents and striæ in various directions, and very singular cross wave-like indents, which we thought must have been due to a rocking motion. The curved striæ at A. fig. 5, Plate 2, had an average direction of N. 42° W. This was ascertained by marking the true N. and S. on the top of the boulder before turning it over, and continuing the line round to the bottom when turned over. The rock on which the boulder rested was very irregular, but there

were striæ on the rock not far off. There is a general tendency of all the markings to trend to the north-west, but they vary. The sketches of the boulder referred to will make the description clearer.

The overlying Boulder Clay in the Poulton cutting (fig. 1, Plate 1), which is the Low-level Marine Boulder Clay of Lancashire and Cheshire, is very clearly and distinctly divided by a bed of sand, which extends the whole distance from Cinder Lane to Mill Lane. The clay above the sand bed is what is locally known as "top clay," and that below the sand bed as the "bottom clay."

The difference between the clays is great, the top clay being soft and easily dug out, the bottom clay extremely hard and tough. The effect of the late severe frosts on the two clays is remarkable: the top clay was not affected, but the bottom clay was, to the depth reached by the frost, simply turned into mud.

Specimens of the three beds were submitted to Mr. Joseph Wright, F.G.S., of Belfast, distinguished for his researches on the Foraminifera of the Boulder Clay. He thoroughly examined them microscopically, and reported as follows :—

"No. 1 (Upper Clay).—Soft muddy clay, weight 2 lbs. 6 ozs. After washing through sieve, 10 ozs. fine, 1 oz. stones, some rounded. Foraminifera very rare. *Nonionina depressula* (W. and J.) rare.

No. 2, very fine sand (Shore-line).—Weight 2 lbs. After washing through sieve 2 ozs. fine, ⅛-oz. stones, some rounded. No Foraminifera.

No. 3 (Bottom Clay).—Exceedingly fine sandy clay, weight 1 lb. 14 ozs. After washing through sieve 7 ozs. fine, ½-oz. stones, some rounded. Foraminifera very *abundant*.

Miliolina seminulum (Linn.), rare.
,, *subrotunda* (Mont.), very rare.
Verneuilina spinulosa (Rss.), very rare.
Bulimina pupoides (d'Orb.), rare.
,, *fusiformis* (Will.), very rare.
,, *elegantissima* (d'Orb.), very rare.
Bolivina punctata (d'Orb.), rare.
,, *plicata* (d'Orb.), common.
,, *dilatata* (Rss.), rare.
Cassidulina crassa (d'Orb.), frequent.
Lagena lineata (Will.), rare.
,, *Williamsoni* (Alcock), rare.
,, *squamosa* (Mont.), rare.
,, *lucida* (Will.), very rare.
Uvigerina angulosa (Will.), frequent.
Globigerina bulloides (d'Orb.), frequent.
Orbulina universa (d'Orb.), very rare.
Pullenia sphæroides (d'Orb.), rare.
Discorbina rosacea (d'Orb.), rare.
,, *sp.*, rare.
Truncatulina lobatula (W. & J.), very rare.
Nonionina depressula (W. & J.), very common.
Polystomella striatopunctata (F. & M.), rare."

Mr. Wright remarks: "No. 1 yielded only 3 specimens, No. 2 none, whilst in No. 3 they were in great profusion. I picked out of No. 3, 450 specimens, 380 of them being referable to one species, viz., *Nonionina depressula*. I was not surprised at finding none in No. 2, sandy deposits, as a rule, contain few organisms of any kind. Two of the species are exceedingly rare as recent British forms. *Pullenia sphæroides* has only been recorded as British by Mr. J. D. Siddall, who got it in the Dee, and Mr. Balkwill and myself, who dredged it off Dublin—two specimens in all. *Verneuilina spinulosa* is equally rare.

Mr. Siddall got it from the Dee, Dr. Brady from Galway, and Mr. Balkwill and myself from the Irish Sea."

The Boulder Clay and sand contains the usual shells and shell fragments distinguishing the Low-level Marine Boulder Clay of Lancashire and Cheshire. During the progress of the works the following species were picked up in a specially perfect condition They were submitted to Mr. R. D. Darbishire, F.G.S., who kindly examined them:—

1. *Leda pernula* (shore, Seacombe).
2. *Turritella*.
3. *Dentalium entale* (in clay).
4. *Pleurotoma* [*? rufa*, worn] (in clay).
5. *Trophon clathratus* (shore-line, Poulton).
6. *Turritella terebra* do.
7. *Turritella*, much older shell (shore-line, Poulton).
8. *Littorina littorea* (in clay).

9, 10. *Tellina Balthica* do.

11. Fragment *Cyprina Islandica* (in clay).

The riddlings of 9½ lbs. of sand from the shore line yielded a goodly number of minute shell fragments. In this 9½ lbs. were 2½ lbs. of clay balls (to be presently described), clay lumps, and gravel.

Mr. Darbishire recognised the following species:— *Cardium edule Dentalium, Turritella, Tellina, Balanus*, and 100 indeterminate fragments.

A batch of shell fragments was also collected off the slopes of the cutting below the shore-line: they may have come from any of the three beds:—

1. *Balanus*.
2. *Ostrea edulis*.
3. *Cardium echinatum*.
4. ,, *edule*.
5. *Pecten opercularis*.

6. *Mya truncata.*
7. *Leda pernula.*
8. *Modiolus.*
9. *Astarte Borealis.*
10. *Turritella terebra.*
11. *Nasa reticulata.*
12. *Purpura lapillus.*
13. *Fusus antiquus.*
14. *Trophon clathratus.*

In addition to these Mr. Davies picked up off the embankment made from the cuttings in the drift an enormous *Turritella*, which Mr. Darbishire, together with authorities in London to whom he showed it, agree is a large *Turritella communis* (*terebra*). Unfortunately it was not known from which bed it came, but we have little doubt from its condition that it is a true drift specimen. It is in a chalky condition, and filled with drift matter. It is now in the possession of Mr. Darbishire. It measures 4 in. long (restored), and ⅞ in. diameter at the broadest end.

The intermediate bed of sand with occasional fine gravel, referred to as the "shore-line," is remarkable, as containing throughout its entire length balls of clay varying in size from ¼ in. to 2½ in. diameter. Some are quite spherical and others ellipsoidal in shape, and often very perfectly formed. The cores of these balls were simply clay similar to the underlying Boulder Clay, but the outside crust was composed of a hard covering of sand and particles of shells, and sometimes fine gravel in concentric layers. Out of 100 specimens cut open, not one contained a shell or any other substance round which the ball might have been formed, the nucleus being simply amorphous brown clay. They are, to all intents and purposes, simply clay boulders or pebbles.

Upon placing these balls in water while moist, the following were the results * :—Small particles were constantly dislodged from the outside crust. This goes on for three to five weeks, when the outside casing is dissolved, and then the balls crack in two or three pieces vertically, as shewn in fig. 8, Plate 2.
These pieces gradually break up into smaller pieces. The fractures show no signs of the mass of the balls having been formed by accretion in concentric shells. They are clay boulders, and formed out of lumps of clay rolled and rounded by water.

As showing the conditions under which these balls were formed, it is an important fact, established by our experiments, that under water sand cannot be made to adhere to clay. Take a lump of clay in the hand and roll it about in sand under water, and no sand will adhere to the clay; but take the wet clay out of the water and then roll it in sand either wet or dry, and it will be found that a thin coating of sand will stick to the clay. If this process is repeated daily for about a month, the ball in the meantime being kept in damp sand, we get a clay ball covered with thin concentric layers of hard sand, exactly like those found in the cutting.

It may be possible for the clay balls without the sandy crust on the outside to be formed entirely under water by continual rolling about, but it is quite impossible for the hard sandy crust to be formed without exposure to the air. For the production of a thick casing like the clay balls in the Poulton cutting, the balls must have been first wetted and then partially dried a great many times.

The level of this bed at Cinder Lane is 42 feet above O.D., and, near Mill Lane, about 66 feet. The balls are

* If the balls were dried first and then placed in water, they fell to pieces in a few moments.

in the greatest profusion at the lower levels and about the middle, very few being met with at the upper level. The extreme vertical range of the sand-encased balls is thus 24 feet, which corresponds approximately to the tidal range at the present time.

Although the sand bed shows in the section in a curved line rising towards Poulton, it is probably approximately a plane with a dip of 1 in 66 to the S.E., the appearance on the section being caused by the two reverse curves on the railway intersecting the bed at varying levels.

In excavating the sewer diversion at Sherlock Lane this same bed or shore-line was traced for about 2 chains on the north side of the railway, and about 5 chains on the south. We have thus a proved width of about 150 yards at this point. Also, in the new brick-fields between Mill Lane and Love Lane this bed can be traced for about 100 yards on the north side of the railway.

The whole length of the sand-bed, extending a distance of 600 yards, yields a constant and uniform supply of water of about 2,000 gallons in 24 hours, which is not affected much by dry weather—another fact pointing to its being of considerable area.

There can therefore be no doubt that the bed is very extensive, and would probably, could it be bared, be found to be approximately a plane surface such as is presented by a sandy shore of the present day.

In the lower reaches (Sherlock Lane to Cinder Lane) of this sand bed, shells—chiefly *Turritella terebra*—were found in great profusion, and in a very good state of preservation.

It has, we understand, been suggested that this sand bed might have been formed by a sub-glacial stream, and that the sand and the shells are merely derived from the

washings of the Boulder Clay. Against this view we have the fact that the shells in the sand-bed are in a better state of preservation than the shells in the clay beds below or above. Also, the sand is too fine to have been laid down by a rapid current, and there is an entire absence of large boulders in the sand-bed.

At the Seacombe end of the railway the cutting (C to D, fig. 2, Plate 1), is in Boulder Clay, and here again there is a division of two clays by a sand-bed, though not so prominently as at Poulton.

The only solid strata touched in the Seacombe cutting were the pebble beds of the Bunter, about 21 feet below the surface at Parry Street, but the surface of the rock was too soft to retain any striæ.

Immediately above the rock was clean sand, and above this a very stiff clay full of boulder stones, mostly striated, some being remarkably polished, specimens of which we show.

The dividing line between the upper and lower clay is not so clearly shown as in the Poulton cutting, the sand having probably been eliminated from the greater portion of the length of the cutting: however, the parting line could be easily traced for the whole distance. This parting line in some places opens out to a bed of sand 1 ft. 6 in. thick, which in several places yielded clay balls; but the clay balls found here were not coated with sand as at Poulton, thus showing that they were probably formed under different conditions.

Towards the east end of the cutting the sand gives place to pebbles, much worn after striation. Some of these pebbles are curiously indented: we show a few specimens of these.

Specimens of the clays above and below the sand

seam yielded the following results on being mechanically analysed by fine sieves :—

SEACOMBE RAILWAY CUTTING.

Clay No. 1, from above Shore-Line.

Weight before washing=5 oz.

Weight after washing—

Caught in 1-20 inch mesh	.. ..	·054
,, 1-40 ,,	.. ..	·020
,, 1-100 ,,	.. ..	·095
Passed 1-100 ,,	.. ..	·195
Sand and gravel	.. ..	·364
Clay	.. ..	·636
		1·000

The material caught in the 1-20 in. mesh consisted of a fragment of a pebble of hard grit ⅜ in. in diameter (Silurian?), dark, irregularly shaped pieces of drift rocks, grains of quartz, many minute fragments of shells worn smooth at the edges, small grains of red marl.

1-40 mesh. Granules same as above but a much larger proportion of quartz grains, many of them highly polished and rounded ;* a good sprinkling of shell fragments. In mass, the colour is reddish brown.

1-100 mesh. Mostly very fine quartzose sand of a yellowish shade in bulk. Some of the grains much worn; a good many shell fragments.

Passed 1-100 mesh. Practically extremely fine quartzose sand, almost impalpable.

It is remarkable that this top clay—though, as the analysis shows, it differs little from the bottom clay, No. 2—was naturally very much harder and more difficult to work.

SEACOMBE RAILWAY CUTTING.

Clay No. 2, from below Shore-Line.

Weight before washing=4 oz.

Weight after washing—

Caught in 1-20 inch mesh	.. ..	·026
,, 1-40 ,,	.. ..	·015
,, 1-100 ,,	.. ..	·161
Passed 1-100 ,,	.. ..	·203
Sand and gravel	.. ..	·405
Clay	.. ..	·595
		1·000

*The grains of the Keuper Sandstone at Poulton are angular, and of the Bunter sub-rounded in most instances, a few being perfectly rounded, but not to compare with those of the 1-40 mesh.

The material caught in 1-20 mesh consists of rolled and angular drift stones; a fragment of red granite, with black mica; mica flakes; quartz grains, some rounded; grains of red marl; a good many shell fragments.

The material caught in 1-40 mesh consists of grains of drift rocks; a large proportion of quartz grains, a great many very much rounded and polished; many shell fragments—one pearly-looking, like the inside of an oyster.

The material caught in 1-100 mesh consists of fine-grained quartz shore-sand, the grains of all shapes but generally much worn, rounded, and polished for such small grains; a few grains of drift rocks, and some fragments of shells.

Passed 1-100 mesh. Mostly angular splinters of quartz with clayey matter adherent.

These clays when dried became very compact and hard.

The fine material in both cases, which is the more purely clay, was in unusually large proportion, twice as much as in the clay from the Bog Hall Brickworks near Bray,* of which bricks are actually made. The clay was not unlike that in the section of the Atlantic Docks ("Drift Beds of the N.-West of England."—Q.J.G.S., 1883, p. 88), marked No. 4. This clay was examined by Mr. David Robertson, F.G.S., who divides it into 58 per cent. of fine mud, 20 of sand, and 20 gravel. He named 22 species of Foraminifera from this bed (p. 130).

Specimens of the clays, of which the mechanical analyses have just been given, taken at the same time from the Seacombe cutting at the point marked *a* on Section, were submitted to Mr. Joseph Wright for examination for Foraminifera. He reports as follows:—

"No. 1 Clay, Seacombe Cutting.—Weight 3 lbs. 6 oz. After washing through sieve fine 8 oz., coarse 1 oz. Foraminifera plentiful.

* See "Dublin and Wicklow Shelly Drift."– Proc. of L'pool Geol. Soc., 1893–4, p. 190.

Bulimina fusiformis (Will.), very rare.
Bolivina plicata (d'Orb.), rare.
,, *dilatata* (Rss.), very rare.
Cassidulina crassa (d'Orb.), very rare.
Lagena Williamsoni (Alcock), very rare.
,, *semistriata* (Will.), very rare.
,, *lævigata* (Rss.), very rare.
,, *orbignyana* (Seg.), very rare.
Uvigerina pygmæa (d'Orb.), very rare.
,, *angulosa* (Will.), very rare.
Globigerina bulloides (d'Orb.), frequent.
Discorbina rosacea (d'Orb.), very rare.
Polystomella striatopunctata (F. & M.), frequent.
Nonionina depressula (W. & J.), very common.

It is remarkable that in this clay there were about 1,000 specimens of *Nonionina depressula*, whilst the remaining 13 species numbered in all only 34 specimens.

No. 2 Clay, Seacombe Cutting.—Weight 3 lbs. 14 oz. After washing through sieve fine 8 oz., coarse 2 oz. Foraminifera plentiful.

Miliolina seminulum (Linn.), frequent.
Bulimina pupoides (d'Orb.), rare.
,, *marginata* (d'Orb.), very rare.
Bolivina plicata (d'Orb.), frequent.
,, *dilatata* (Rss.), very rare.
Cassidulina crassa (d'Orb.), rare.
Lagena globosa (Mont.), rare.
,, *sulcata* (W. & J.), very rare.
,, *Williamsoni* (Alcock), very rare.
,, *squamosa* (Mont.), very rare.
,, *hexagona* (Will.), very rare.
,, *marginata* (W. & B.), very rare.
,, *lucida* (Will.), very rare.
Polymorphina rotundata (Born.), very rare.

Uvigerina angulosa (Will.), rare.
Globigerina bulloides (d'Orb.), rare.
,, *æquilateralis*, Brady, rare.
Truncatulina lobatula (W. & J.), rare.
Nonionina depressula (W. & J.), very common.
Polystomella striatopunctata (F. & M.), rare.

The Foraminifera in the clays are such as might be found in almost any shallow water muddy bottom around our coast.* The enormous profusion of *Non. depressula* at No. 1 is remarkable. I found this species equally abundant in two packets of glacial clays which I recently examined.

One of these was from Ballyhornan Bay, County Down, recorded by the Geological Survey as Middle Boulder Clay. This sample yielded one specimen of *Truncatulina lobatula* and about 400 of *Nonionina depressula* and *Polystomella striatopunctata*. The other from Colligan Bridge, Co. Down, at an elevation of about 400 feet, yielded 37 species. In this case out of about 2,300 specimens, some 2,000 were referable to *Nonionina depressula* and *Polystomella striatopunctata*."

Throughout the whole of the cuttings the clays both of Poulton and Seacombe contained the usual erratic stones, in the form of boulders and pebbles, which are met with in the Low-level Marine Boulder Clays of

* Mr. Wright calls attention to the fact that the Foraminifera of the Boulder Clays are usually of a smaller size than species of the same sort now found on our coasts, and these from Poulton and Seacombe are no exception. At Ballyrudder, on the Antrim coast, the following Foraminifera from the Boulder Clay were measured and found to be less than recent British forms, in the proportions stated below—measured in *volume*, not in *diameter*:—

Globigerina bulloides	$\frac{1}{25}$
Orbulina universa	$\frac{1}{70}$
Truncatulina lobatula	$\frac{1}{125}$
Nonionina depressula	$\frac{1}{4}$
Rotalia Beccarii	$\frac{1}{65}$
Polystomella crispa	$\frac{1}{65}$

Lancashire and Cheshire, among which Lake District Silurians and Volcanics predominated.

Eskdale and other granites were found, together with Carboniferous limestone, chert, &c. The greatest proportion of the stones occurred at the base of the clay, and these were mostly rounded. The largest boulders were found in the upper clay. Many of the stones were planed and striated. The upper clay at Seacombe, as already stated, was much more compact and harder than the lower clay, and very much more difficult to work. At Poulton the top clay was hardest. In consequence of the discontinuity of the sections it is difficult to correlate the clays of Poulton and Seacombe. As a whole the clays cannot be considered very stony, nor were there any large erratics found, the largest being the Silurian grit boulder at Poulton, already described in detail. The boulders lie in the clay in all positions, some flat and some canted, and the directions of the striæ on the stones follow no rule. This applies to both Poulton and Seacombe. This is the result of twelve months' close observation. The Boulder Clay increases in thickness towards Wallasey Pool. A well boring recently made at Buchanan's Flour Mill showed 68 feet of Boulder Clay resting on 2 feet of sand, below which was 20 feet of light coloured sandstone, the rest—175 feet—being in the Red Sandstone (Bunter ?).

CONCLUSION.

The first notice of this cutting is in a paper by one of us, entitled "An Ancient Glacial Shore," published in the Geological Magazine, February, 1894, p. 75. It was there contended that the clay balls or boulders were an indisputable evidence of shore conditions. Since then Prof. N. H. Winchell, in a communication to the

Glacialists' Magazine,* describes clay boulders in the drift in the banks of the Rum River (Mille Lacs), County Minnesota, 1,000 feet above sea-level, which he considers must have been formed by a running stream, as their position precluded marine action. They varied in size from four to eight inches. Our member, Mr. Lomas, is inclined to look upon the clay balls as the product of water flowing from under an ice sheet. These views induced us to pay particular attention to the bed in which the clay balls occurred, and their mode of occurrence.

Without in any way calling in question Professor Winchell's deductions from the phenomena observed by him for the locality in which they were observed, we consider that the facts as stated by us in the foregoing pages are conclusive as to this sand bed being formed under marine shore-conditions. The extent or area of the deposit with clay balls, of which there must be millions coated with sand, does not favour the view of stream action, which could not without straining natural conditions be supposed capable of laying down such an uniform bed of sand. Rather, the stream would have cut vertically into the soft Boulder Clay below, and somewhere in the extensive sections disclosed we should have seen eroded channels, or somewhere or other sections of vertical or steep banks in connection with the sand bed. Nothing of the sort occurred.

Again, it is shown by our experiments that the clay balls could not become encased with concentric layers of sand and shells if they were formed entirely under water; and this introduces tidal range as the most reasonable explanation of the alternate wetting and drying required for the formation of the external cases of these clay balls.

* "Pebbles of Clay in Stratified Gravel and Sand."—Glacialists' Mag., March, 1894, pp. 1716–17.

The extremely interesting result of Mr. Wright's examination of the clays considerably strengthens the contention of the marine origin of the whole.

The Bottom Clay, No. 3, at Poulton, and both the clays at Seacombe, contain a profusion of Foraminifera, and these, as Mr. Wright says, are usually found in shallow water deposits of fine mud in our present seas. All this converging evidence multiplies one hundred-fold the probabilities of the whole of the drift here having been formed under marine-glacial conditions, and if so, points strongly to the more than probability that the whole of the Low level Clays and Sands of Lancashire and Cheshire, which are similar in constitution and mode of occurrence, have been formed in the same way.

The presence of the shore-line with clay balls makes a more marked distinction between the lower and upper clays than is usual. Such divisional beds of sand, having considerable continuity, are shown in the Sections of the Cheshire Lines, Liverpool Extension Railway (Q.J.G.S., 1883, p. 90), and this shore-line at Poulton is really the best evidence we have yet seen in favour of a division of the drift, and at one time would doubtless have been considered conclusive. It was also observed by us that the clay balls are destroyed rapidly by frost, hence we may infer that the conditions were not very severe when they were formed. Still, this is insufficient evidence on which to found an "interglacial period." The bulk of the Boulder Clays of Lancashire and Cheshire have been formed in comparatively shallow water when the land was extensive enough to yield the necessary quantity of materials of which they are composed, and not when the submergence was at its maximum. Probably the land remained submerged to the extent of several hundred feet with minor oscillations

during a long period, and in this way some of the anomalous phenomena and the Upper and Lower Clays of Poulton can be accounted for.

As regards the striæ on the bed rock and the disturbance of the mass of rock at Poulton described in the preceding pages, we are of opinion that there is not sufficient known of the action of land or sea ice to justify any decided opinion. Suggestions could be made, but we refrain, considering the existing controversy that now rages between two classes of glacialists, which, whatever else it does, certainly stirs up geologists to further and more minute observation.

In many respects the subject, whatever view is taken, is full of difficulties, which let us hope will be eventually solved; though we fear it will be long before agreement is reached.

REPORT OF EXCURSION TO APPLEBY, EASTER, 1895.

A PARTY consisting of Messrs. Hewitt, Goffey, Rock, Bruce, Mawby, Morgan and Lomas, arrived at Appleby on April 11th, and put up at the "Tufton Arms" Hotel.

On the 12th a joint excursion with a party of Geologists from Yorkshire College, Leeds, was made to Keisley and High Cup Gill.

The Permian sandstone, near Appleby, was first examined, and just before crossing the Penine Fault, near Harbour Flat, a faulted outlier of Carboniferous Limestone was visited.

At Keisley the Limestone quarries were examined. The beds showed much crumbling, one being inverted, and Carapaces of Illœnus were seen on its lower surface. Several minor faults showing vertical and horizontal slickensides occur in the quarry.

On the way to High Cup Nick, the inner Penine Fault was crossed, and Mountain Limestone was traversed to the head of the valley. Near the top, a great sheet of Whin Sill is exposed, and junctions were obtained with the mountain limestone overlying it.

On the way back, along the south side of the valley, several Moraines were noted.

On the 13th a traverse was made across the strike of the beds from Coupland Mill to Hilton and Roman Fell.

The Brockram at Coupland Mill dips N.E. 20°, and consists mainly of Carboniferous pebbles, sometimes dolomitised and chertified. Many of the pebbles were hollow, and contained well-developed crystals of Quartz, &c.

The Permian Sandstone of Brackenber Moor was crossed, and on approaching Hilton Beck more Brockram appeared. Here it exists as thin lenticular patches, and gradually dies out towards Hilton. The Plant beds yielded specimens of Walchia, Ullmannia, and various ferns. Just above the plant beds, a thin bed of Magnesian Limestone is exposed in the bed of the stream. Succeeding this St. Bees' Sandstone comes in, and continues till Hilton Village is passed.

Near a small bridge just below the Smelt Mill, the Penine Fault can be traced, the Permian being thrown down against fossiliferous Lower Silurian.

The igneous rocks at the base of Roman Fell were examined, and some of the party climbed to the summit of Roman Fell.

The 14th was devoted to an excursion to Shap. Driving through the village of Hoff the Brockram was noted, and then the Mountain Limestone, immediately succeeding, continued over Horton Scar to

Shap Wells. Enormous boulders of the Shap granite were passed on the way.

From Shap Wells the journey was taken up Wasdale Beck. Close to the junction of Wasdale Beck and Blea Beck the Upper Coniston limestone was seen, From the basement beds of the carboniferous limestone large Felspars were collected. The dykes at Stakeley Folds and Packhouse Hill were visited, and then the granite quarries of Wasdale Crag were examined. The bosses of granite showed polishing and striation from the West, and glacial deposits containing rocks derived from the West were observed in the quarry.

At Wastdale Farm the Rhyolites and dykes were traced. On the way home we passed through Shap Village, and continued through Newby and Moreland to Appleby.

The junction of the Carboniferous and Permian was noted just after passing Moreland.

On the 15th train was taken to Long Marton, and a short walk over the Permians brought us to Dufton. A quarry in the Permian sandstone is seen just after crossing the stream near Dufton, and in it rain-pittings, ripple marks, and footprints were found. Passing through Dufton, the outer Penine Fault was crossed, and the Dufton Shales near Pusgill House yielded an abundance of Trilobites and other fossils. Continuing along the slopes of Dufton Pike, the quarries of the so-called Dufton Granite were examined. The exposure of the same rock in Hurning Lane was also seen, and Trilobites, &c., were obtained a little lower down from the roadside cuttings.

The next section of interest was along Swindale Beck. On the way the shales in Rundale Beck were examined, and many fossils, including good specimens of Graptolites, were gathered.

At the junction of the two streams two fine dykes of Lamprophyre were found, and higher up Swindale Beck, at the foot of Knock Pike, another dyke appears. Fossils were collected from the various beds exposed in the stream course, and on approaching Knock on the homeward journey the outer Penine fault was accurately traced.

On the return to Appleby the Brockram quarry at Hungriggs was visited.

The 16th was devoted to an examination of the fine Brockram escarpments near Hoff. The junction with the Carboniferous was made out at various points.

Along Hoff Beck the sandy banks were seen at places to contain rolled clay balls, which had evidently been formed by river action.

J. LOMAS.

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OF THE
LIVERPOOL GEOLOGICAL SOCIETY.

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MOLYNEUX, THOS., Earlestown, Newton-le-Willows.

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*POTTER, C., 101, Miles Street.

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ROCK, W. H., 75, Botanic Road.

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*WARD, T., Brookfield House, Northwich.

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DOUGLAS, Miss RHODA, 2, Moss Lane, Orrell Park, Aintree.

READE, A. L., Park Corner, Blundellsands.

TWEDDLE, D., Walmer Road, Waterloo.

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* Have read Papers before the Society.
† Contribute to Printing Fund.

LAWS OF THE

Liverpool Geological Society,

As Revised November, 1894.

Object.

To investigate the structure and history of the Earth, the character of its past inhabitants, and the changes now in progress upon its surface.

Constitution.

The Society shall consist of Ordinary Members, Associates, and Honorary and Foreign Correspondng Members, and its proceedings shall be governed by the following Laws.

Ordinary Members and Associates.

No. 1.

The annual subscription for Ordinary Members shall be one guinea, but for Members residing more than 15 miles from the Liverpool Exchange, half a guinea. Subscriptions shall be payable in advance on the 1st day of October in each year, and each Member shall be entitled to receive a copy of the publications of the Society issued during his membership. (Members of the Society elected before March, 1873, shall have the option of continuing the old rate of subscription, viz.:—Five Shillings for non-resident Members, and Ten Shillings and Sixpence for resident Members.)

No. 2.

No Member whose Subscription is in arrear, for any but the current Session, shall be entitled to take part in the proceedings of the Society, and if any Member omi to pay his Subscription for two successive years, th Council shall have power to remove his name from the lis of Members.

No. 3.

Any Member may resign upon paying all Sub scriptions due, and giving a written notice of hi intention to the Secretary, who shall lay it before th Society at its next Meeting.

No. 4.

Every Candidate for Membership shall be propose in writing by two Members of the Society, one of whon shall have personal acquaintance with him. The nam and address of the Candidate, and the names of th Proposers shall appear on the circular calling the nex following Meeting, and the election shall take place b ballot at that Meeting.

No. 5.

Associates shall pay an Annual Subscription of te shillings and sixpence (or if residing more than 15 miles fron the Liverpool Exchange a Subscription of six shillings) They shall be entitled to be present at all the Ordinar Meetings of the Society, but shall not be entitled to vot nor be eligible for office. They shall be entitled t purchase a copy of the Proceedings each year during thei term of membership at half the published pric They shall be elected in accordance with and be subject t the laws laid down for Ordinary Members.

No. 6.

A Member may become a Life Member by the payment of the sum of ten guineas.

No. 7.

No Member shall be expelled from the Society except by the votes of four-fifths of the Members present, and entitled to vote, at an extraordinary Meeting convened for that purpose.

Honorary and Corresponding Members.

No. 8.

Anyone distinguished for attainments in Geology, or who shall have promoted the objects of the Society in any special manner, may be elected an Honorary Member, and any Foreign Geologist of distinction may be elected a Corresponding Member. Each Honorary and Corresponding Member shall be entitled to receive a copy of the publications of the Society from the date of election.

No. 9.

A Member proposing a Candidate for Honorary or Corresponding Membership shall have previously obtained the consent of the Candidate. The election shall then be decided according to the law laid down for Ordinary Members.

No. 10.

Honorary and Corresponding Members shall have no vote in the business of the Society.

Officers.

No. 11.

The Officers of the Society shall be a President, Vice-President, Secretary, Treasurer, and Librarian.

All acts of the Society shall be determined by a major the votes of the Members present, except in those inst where special provision is made to the contrary.

No. 31.

The order of business at the Meetings of the S shall be as follows:

1.—The Society constituted.
2.—Minutes of the last Meeting read and signed.
3.—Donations announced.
4.—Communications from the Council.
5.—Applications for admission received.
6.—Applications for admission determined.
7.—New Members admitted.
8.—Visitors introduced.
9.—Miscellaneous Communications and Exhibits rec
10.—Papers read and discussed.
11.—Next Meeting and Papers for the occasion annou

No. 32.

All additions to or changes in these Laws sh determined by a majority of votes at an Extraord Meeting of the Society, convened for that purpose.

C. TINLING AND CO., PRINTERS, VICTORIA STREET, LIVERPOOL.

PROCEEDINGS

OF THE

Liverpool Geological Society.

SESSION THE THIRTY-SEVENTH,

1895-96.

Edited by H. C. BEASLEY.

(The Authors, having revised their own Papers, are alone responsible for the facts and opinions expressed in them.)

PART 4. VOL. VII.

LIVERPOOL:
C. TINLING AND CO., PRINTERS, VICTORIA STREET.
1896.

OFFICERS, 1895–96.

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Ex-President:

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Vice-President:

J. LOMAS, A.R.C.S., London.

Hon. Treasurer:

THOS. COFFEY.

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Council:

T. W. DAVIES, C.E.
A. R. DWERRYHOUSE
W. HEWITT, B.Sc.
W H. ROCK
C RICKETTS, M.D., F.G.S.

LIST OF SOCIETIES, ETC., TO WHICH THE PROCEEDINGS OF THE LIVERPOOL GEOLOGICAL SOCIETY ARE SENT.

*(Publications have been received in exchange during the Session from those marked *.)*

*Academy of Natural Sciences, Philadelphia.
Advocates' Library, Edinburgh.
*Australian Museum, Sydney.
*Belfast Naturalists' Field Club.
*Birkenhead Free Public Library.
,, Literary and Scientific Society.
Birmingham Philosophical Society.
Bootle Free Public Library.
British Museum.
British Museum (Natural History) Geological Department.
*British Association for the Advancement of Science.
Bristol Naturalists' Society.
Bodleian Library, Oxford.
*Boston Society of Natural History, U.S.A.
*Chester Society of Natural Science.
*Colorado Scientific Society.
Dudley and Midland Geological and Scientific Society.
Essex Naturalists' Field Club.
Editor of "Geological Record."
,, "Nature."
,, "Geological Magazine."
,, "Science Gossip."
,, "Glacialists' Magazine."
Ertborn, Le Baron O. Van, Anvers, Belgique.
Geological Society of Edinburgh.
Geological Society of Glasgow.
*Geological Society of London.
*Geological Society of Manchester.
Geological Society of Norwich.
*Geological Society of Australasia, Melbourne.
*Geological Survey of the United States.
Geological Survey of India.
*Geological Survey of Canada.
*Geological Survey of Missouri.
*Geological and Natural History Survey of Minnesota.
*Geological Survey of Sydney, N.S.W.
Geological Survey of Arkansas.
*Geologists' Association, London.
*Glasgow Philosophical Society.
Herts Natural History Society.
Hungarian Karpathian Society, Locse.
*Imperial Academy of Naturalists, Halle, Prussia.
Kansas Academy of Sciences, Topeka, U.S.A.

*Leeds Philosophical and Literary Society.
*Leeds Geological Association.
Liverpool Athenæum.
" Chemists' Association.
* " Free Public Library.
* " Geological Association.
* " Literary and Philosophical Society.
" Lyceum Library.
" Philomathic Society.
* " Engineering Society.
" Astronomical Society.
" Science Students' Association.
L'Universite Royal de Norvége, Christiana.
*Manchester Association of Engineers.
*Manchester Literary and Philosophical Society.
*Manchester Geographical Society.
*Minnesota Academy of Natural Science, Minneapolis, U.S.A
Musée Royal d'Histoire Naturelle de Belgique.
Museu Nacional, Rio de Janeiro.
Museum of Practical Geology, Jermyn Street, London.
*Natural History Society of New Brunswick, St. John, N.B.
*North of England Institute of Mining and Mechanical Engineers.
*New York Academy of Sciences.
*Owens College, Manchester.
Patent Office Library, 25, Southampton Buildings, Chancer Lane, London, W.C.
Rassegna delle Scienze Geologiche in Italia.
*Rochester, N.Y., Academy of Science.
*Royal Dublin Society.
Royal Geological Society of Ireland, Dublin.
Royal Society, London.
*Smithsonian Institution, Washington, U.S.
*Société Geologique de Belgique, Liége.
Société Geologique du Nord, Lille.
*Société Impériale des Naturalistes de Moscow.
*Société Royale, Malacologique de Belgique.
*Sociedade de Geografia de Lisboa.
*Toscana Societa di Scienza Naturali.
University Library, Cambridge.
University College, Bangor.
" " Liverpool.
Warwickshire Natural History and Archæological Society.
*Wagner Free Institute of Science, Philadelphia.
*Wisconsin Academy of Sciences, Arts, and Letters, Madiso U.S A.
Woodwardian Museum, Cambridge.
*Yorkshire Geological and Polytechnic Society.

PROCEEDINGS

OF THE

LIVERPOOL GEOLOGICAL SOCIETY.

SESSION THIRTY-SEVENTH.

OCTOBER 8TH, 1895.

The PRESIDENT, T. MELLARD READE, Esq., C.E., F.G.S., in the Chair.

The Treasurer's Statement was adopted.

The following gentlemen were elected Officers and Members of the Council:—

Vice-President—J. LOMAS, A.R.C.S., London.

Hon. Treasurer—THOS. GOFFEY.

Hon. Librarian—J. J. FITZPATRICK.

Hon. Secretary—H. C. BEASLEY.

Members of Council—T. W. DAVIES, C.E., W. HEWITT, B.Sc., A. R. DWERRYHOUSE, W. H. ROCK, C. RICKETTS, M.D., F.G.S.

The PRESIDENT then read the Annual Address:—

BRITISH GEOLOGY IN RELATION TO EARTH-FOLDING AND FAULTING.

NOVEMBER 12TH, 1895.

The PRESIDENT, T. MELLARD READE, Esq., C.E. F.G.S., in the Chair.

Miss BLANCH C. STALEY, Seafield School, New Brighton: proposed by H. C. Beasley and J. J. Fitzpatrick, was elected an Associate.

Mr. JAS. EDWARD HUGHES, The Willows, Childe Thornton: proposed by Thos. Goffey and H. C. Beasley was elected an Ordinary Member.

The following Papers were read :—

A CONTRIBUTION TO THE DYNAMICAL THEOR OF THE CRAVEN HIGHLANDS.

By Rev. FRED. F. GRENSTED, M.A.

OBSERVATIONS ON RECENT GLACIAL STRIÆ IN SWITZERLAND.

By J. LOMAS, A.R.C.S., LONDON.

FORAMINIFERAL BOULDER CLAY AT GREAT CROSBY.

By T. MELLARD READE, C.E., F.G.S.

DECEMBER 10TH, 1895.

The PRESIDENT, T. M. READE, Esq., C.E., F.G.S. in the Chair.

Mr. JOSEPH WRIGHT, F.G.S., Belfast: proposed by T. M. Reade, C.E., F.G.S., and H. C. Beasley, was, a the suggestion of the Council, elected an Honorary Member.

Mr. A. K. BULLEY, West Kirby: proposed by J. J Fitzpatrick and H. C. Beasley, was elected an Ordinary Member.

Prof. CARUS WILSON exhibited some decayed and decaying Flints, and described the causes and process of decay.

The following Paper was read:—

AN ATTEMPT TO CLASSIFY THE FOOTPRINTS FROM THE TRIAS OF THIS DISTRICT.

By H. C. BEASLEY.

JANUARY 14TH, 1896.

The PRESIDENT, T. MELLARD READE, Esq., C.E., F.G.S., in the Chair.

Mr. THOS. COPE, 2, Lord Nelson Street: proposed by H. C. Beasley and T. M. Reade, C.E., F.G.S., was elected an Ordinary Member.

EXHIBITS—

Photographs of some of the Dartmoor Torrs. Dr. Ricketts.

Fossil Fish from Mount Lebanon. J. J. Fitzpatrick.

"Natural Soap" from the Caucasus. The President.

Supposed worm borings and other traces of life from the Longmynd Rocks. H. C. Beasley.

Graptolites. Messrs. Dwerryhouse, Mawby, Beasley, and the President.

The following Papers were read:—

ON THE RECENTLY PROPOSED CLASSIFICATION OF THE GRAPTOLITES.

By J. LOMAS, A.R.C.S.

NOTES ON THE DRIFT OF THE MID-WALES COAST.

By T. M. READE, C.E., F.G.S.

FEBRUARY 11TH, 1896.

The VICE-PRESIDENT, J. LOMAS, Esq., in the Chair.

Mr. T. W. Davies, C.E., mentioned that the excava tion of a sewer in Martin's Lane, Liscard, had shown th presence there of what appeared to be the Keuper Marl

The following Paper was read :—

THE BERWICKSHIRE COAST; A STUDY IN PHYSICAL GEOLOGY.

By T. M. READE, C.E., F.G.S.

MARCH 10TH, 1896.

The PRESIDENT, T. MELLARD READE, Esq., C.E F.G.S., in the Chair.

Mr. A. R. Dwerryhouse exhibited a collection o fossils from the Isle of Wight, and a series of lanter views of sections on the coast of the island, which h described.

The following Paper was read :—

NOTES ON ZEOLITES FROM NEW JERSEY.

By W. MAWBY.

APRIL 14TH, 1896.

The PRESIDENT, T. MELLARD READE, Esq., C.E F.G.S., in the Chair.

Mr. E. Dickson exhibited a sample of clay fror Kolguev Island, and gave the analysis. Also a sampl of the fine deposit from a stream from the Pindar Glacier, Himalayas.

Rock specimens and fossils collected during the Easter excursion were exhibited by several members of the party.

The following Papers were read :—

NOTES ON THE ANALYSES OF TRIASSIC ROCKS FROM THE NEIGHBOURHOOD OF LIVERPOOL.

By E. Dickson, F.G.S., and P. Holland, F.C.S., F.I.C.

A SKETCH OF THE PROCESS OF METAMORPHISM IN THE MALVERN CRYSTALLINES.

By C. Callaway, D.Sc., M.A., F.G.S.

The following Field Meetings were held :—

1895.

May 20.—Hilbre Island; joint meeting with the Biological Society.

,, 23.—Well boring at Ford, on the invitation of Mr. W. A Richardson, C.E.

Aug. 17.—Cuckoo Hill and Hope, Flintshire.

,, 26.—Blackpool, led by Mr. W. Hewitt, B.Sc.

1896.

April 4/6.—Malvern District, led by Mr. C. Callaway, D.Sc., M.A., F.G.S.

THE LIVERPOOL GEOLOGICAL SOCIETY in Account with THOS. GOFFEY, Hon. Treasurer.

SESSION 1894-5.

Dr.	£	s.	d.	Cr.	£	s.	d.
To Rent to October, 1894	5	0	0	By Balance from 1893-4	2	17	3
,, C. Tinling & Co., Printing	21	7	6	,, Subscriptions (for Session)	37	10	6
,, Geological Magazine to June, 1895	0	18	0	,, ,, (Arrears)	0	15	6
,, Palæontological Society, one year	1	1	0	,, ,, Palæontological Society	0	17	6
,, Doling, for Session	6	19	6	,, ,, Printing Fund	0	10	6
,, Hon. Secretary's Expenses, 1893-4	2	7	2	,, Donation	0	10	6
,, ,, ,, 1894-5	1	18	2	,, Sale of "Proceedings"	1	6	2
,, Hon. Treasurer's Expenses	0	4	6				
,, Balance to next Session	4	12	1				
	£44	7	11		£44	7	11

Audited and found correct,

(Signed), { W. HEWITT.
{ W. H. ROCK.

E. & O. E.

(Signed), THOS. GOFFEY,
Hon. Treasurer.

Liverpool, *5th October, 1895.*

PRESIDENT'S ADDRESS.

BRITISH GEOLOGY IN RELATION TO EARTH-FOLDING AND FAULTING.

By T. Mellard Reade, C.E., F.G.S., F.R.I.B.A.

(*Read 8th October, 1895*).

The history of every science may be compared to the ascent of lofty and diversified mountains, in which level benches and plateaux alternate with steep and rugged slopes. The first explorers, beginning at the base, toil upwards, hardly knowing which course to take, and having little idea of the country that lies before and above them. But they toil on, gathering information as they go, until, reaching a level resting-place, they can look back and form a more accurate conception of the country they have traversed. Still, they can see but a little way upwards, much less perceive the summit, but ascend they must, gaining an ever-widening view and grander and more just conceptions of the wide world below.

It is thus that the study of geology has progressed. By the combined operation of an army of explorers a vantage-ground has been obtained from which we are enabled to review our position and determine upon the next point of attack.

The history and succession of the rocks have been traced, their position in time, and in part their location in space—but the latter knowledge can never be complete until the whole world has been surveyed, both above and below the waters; now a seemingly impossible task: yet who shall speak for the future?

By the aid of numerous geologists, both great and humble, of all climes and countries, manfully working towards a common end, the order of succession has been outlined, and a fair but very crude knowledge of the earth's history reached. So far as palæontology and stratigraphy can speak, they tell us a good deal, but we cannot realise the meaning of it all without the aid of correct physical conceptions to reveal the processes of the wonderful earth-history which lies buried under our feet.

It is with this object that I ask your indulgence this evening in mentally travelling with me over the British Isles to see what help we can get from known British geology.

Facts of British Geology.

An examination of a good geological map of England and Wales, such as that known as Greenough's, published by the Geological Society, shows at once that the older rocks from the Cambrian to the Carboniferous constitute the bulk of the more essentially mountain areas.

Thus, North Wales is mainly Cambrian and Silurian; Cumberland and Westmoreland are largely composed of equivalent rocks, surrounded with a fringe of Carboniferous, which, more greatly developed in Northumberland, Durham, Yorkshire, and Derbyshire, forms the mountainous district of the Pennine Chain, the so-called backbone of Northern England. Leaving out of consideration for the moment the pre-Cambrian rocks of Anglesey and Shropshire, it is in the Cambrian and Silurian that the greatest deformations and foldings have taken place. Lying conformably upon the Upper Silurian in Herefordshire and Brecknockshire is the great thickness of Old Red Sandstone, more horizontally developed, but yet in the Beacons of Brecon and the Fans of Car-

marthen rising as mountains from two to three thousand feet high. These are overlaid conformably by the South Wales Carboniferous rocks. In the North the Carboniferous Limestone lies unconformably upon the Silurian, the Old Red being practically absent. These Carboniferous rocks are in places considerably folded, the Pennine Chain itself being an anticlinal axis, while the Devonian and Carboniferous in Somerset and Devon are folded often at high inclinations in the Quantocks and the Mendips.

Surrounding these anticlinal areas, and in the depression between them, the Permian Limestone breccias and sandstones and the Triassic sandstones and marls lie unconformably upon the Carboniferous rocks, and much of this country is hilly, but cannot be correctly designated mountainous. The whole of the group of rocks, from the Cambrian to the Trias, occupy, roughly speaking, the western half of England, including Wales, but the eastern half of England is constituted of a succession of younger formations, from the Rhætic to the Pliocene. The Rhætic constitutes the passage from the Trias to the Lias, and, though nowhere developed on an extensive scale, is interesting as showing a conformable succession which is unbroken through the Oolites to the Upper Cretaceous. Between the Cretaceous and Eocene is an unconformable break representing a great time interval separating the Cretaceous and Tertiary, which is further confirmed by the complete change in the fauna and flora. The Eocene, Miocene, and Pliocene are conformable, and with them ends what is called the solid geology of the country, the succeeding deposits being Pleistocene, Glacial, and post-Glacial, consisting mostly of clay, sands and gravels, boulder-clay, and alluvium.

It is thus seen that the western half of England, together with Wales, possess the mountainous districts *par excellence*, while the eastern half is distinguished by gently undulating or horizontal strata, with sharp folds located in small areas, as in the Isle of Wight, at Purbeck, and the Yorkshire Chalk at Flamborough Head.

That the Lias had formerly extended over a considerable area of the western half is shown by the preservation of outliers in Shropshire, Staffordshire, and Cumberland, and *prima facie* it is probable that the overlying formations have also at one time in geological history been present. To a student of physical geology a glance at the geological map of England is sufficient to show that the outcrop of the Lias extending from the Severn to the Tees is an escarpment of denudation.

It must not be supposed for a moment that Britain represents the normal physiographic condition of the various formations all over the world, and that the mountain areas are always the oldest. Quite the contrary. In the Alps, Himalayas, and Rockies, in the mountains of the Caucasus and Central Turkestan, it is the younger formations that constitute the highest members of the mountain belts, and it is generally conceded that the bulk of the mountain-making in these chains has been geologically a late event.

Of course in great mountain chains we may have, and generally do have, the older rocks, even to the Archean gneisses and schists thrown up and exposed in their axial folds. This, however, as a rule, only shows that the earth movements to which they owe their birth and growth have been extreme and profound, involving the deep-lying sediments, and even their foundation rocks, in the general movement. We thus see that there

is no intimate relationship between the *age* of the rocks of which mountain areas are composed and the existence of the mountains themselves.

The Mountain Areas of England and Wales as related to the thickness of the sedimentary and other deposits of which they are composed.

The Lower Cambrian Rocks of South Wales are estimated to have a thickness of from 3,500 to 4,000 feet, and are supposed to be over 8,000 feet in North Wales. The Upper Cambrian, where well developed, attain a thickness of from 5,000 to 6,000 feet. The Ordovician, or Lower Silurian of the Survey, is estimated at from 12,000 to 25,000 feet; in Shropshire, according to Murchison, 18,000 feet; and between the Menai Straits and the Berwyns, 19,000 feet. The Silurian, or Upper Silurian of Murchison and the Survey, may be 14,000 feet in the north-west of England, and from 3,000 to 6,000 feet in Wales. The total thickness of British Silurians, Lower and Upper, is stated by Murchison to be from 26,000 to 27,000 feet. Thus, from the base of the Cambrian to the top of the Silurian cannot be less than 35,000 feet.

We thus arrive at the grand aggregate thickness of from six to seven miles of rocks constituting the most mountainous parts of England and Wales. These rocks have suffered more intense deformation than any of the overlying formations, and have, as first lucidly explained by Ramsay, suffered enormous denudation since their folding and upheaval.*

The only break in the series of any moment occurs between the Ordovician and Silurian. There can be

* "Denudation of South Wales and the adjacent English Counties": Memoirs of the Geological Survey, vol. i.

very little doubt that their areal extension was proportionately as great as their thickness. Between the Carboniferous and the Silurian there is a strong unconformity in the north of England and North Wales, but this is bridged over, as already explained, in Shropshire, Herefordshire, and South Wales, by the Old Red Sandstone, estimated at 10,000 feet. The Silurian shades upwards into the Old Red by well-defined passage beds, to be seen in many sections, while the Old Red graduates into the Carboniferous in a no less perfect manner.

The Carboniferous is an extensively developed formation in Britain. The base of Mountain Limestone varies in thickness from 1,000 feet in Monmouthshire to 3,000 feet in the Mendips in Somerset, while in Derbyshire it is 1,600 feet, in the Vale of Eden 2,000 feet, and in Llangollen 1,200 feet thick. The Millstone Grit reaches a maximum of 5,000 feet, the Coal-measures of South Wales 7,000 to 8,000 feet, and, according to Logan, reaches 10,000 to 12,000 feet in Monmouthshire, Glamorganshire, and Pembroke. In Lancashire the Coal-measures are 6,600 feet, though the upper portions have been denuded.*

If we add these figures to the Cambrian and Silurian we arrive at a grand total of 55,000 feet, but it is not to be inferred that this occurs in any one place. Ramsay estimates the Silurians, Lower and Upper, the Old Red, and Coal-measures in South Wales at from 20,000 to 33,000 feet (Mem. of Geol. Survey, vol. i., p. 316).

It is of these enormously developed rocks that the typical mountain areas of England and Wales are composed. The question may well suggest itself to us

* The authorities for these statements are principally Murchison and Ramsay, together with other authorities quoted by H. B. Woodward in the "Geology of England and Wales."

whether there is not here a relation of cause and effect. We have seen that, with the exception of the break between the Ordivician and Silurian, there has been continuous deposit of sediment from the beginning of the Cambrian to the end of the Silurian, and still further, that in the Old Red Sandstone districts this sedimentation appears to have gone on almost uninterruptedly to the close of the Carboniferous. It is certainly a striking fact that a portion of the earth loaded with sediment to the vertical extent of some five to ten miles should be the very spot where the earth's crust has been elevated not less than four miles, according to Ramsay, and where even now the basal wrecks of these former gigantic elevations should reach 3,000 feet above the sea-level. Consider for a moment what five miles of consolidated sediment means. It is equal to a load of 2,000 tons per square foot on the normal crust of the earth.

This loading doubtless squeezed and shifted laterally some of the deeply lying and more mobile matter underlying the normal crust, until a balance of stability was attained. Then, by a process of expansion, the effect of a necessary rise of temperature of the old crust and overlying deposits, the conditions were reversed: the lengthening beds, unable to expand, laterally folded upon themselves, and the whole mass of sediment, by cubical expansion, increased in volume to the extent shown, by the rise of the mountain mass above the sea-level. But we are not to limit this action to the immediate mountain area, for the flanking area, probably largely constituted of more horizontal beds, now covered by newer deposits by successive lateral expansions, added to the folding and heaping up of the mountain masses.

Areas occupied by the Rocks newer than the Carboniferous.

If this relation between extensive and massive sedimentation and mountain-making stood alone it might justly be considered as merely accidental. I have, however, elsewhere shown that such relations may be traced in every known great mountain range; that formations here thinly developed and horizontal are in the Alps and Pyrenees, to go no further afield, extensive, thickly developed, and thrown into immense mountain masses.

In Britain the Permian and Trias, which lie unconformably upon the Carboniferous, reach a thickness of some 6,000 feet, but the variation of thickness is very considerable from the overlapping of these formations on the mountain slopes. They are, however, as a rule, more affected by folding and faulting than the succeeding formations, and constitute some considerable hills and escarpments.

The Jurassic and Cretaceous occupy the largest part of the eastern half of England, and may be put down at perhaps 5,000 feet, and the Tertiary at say 1,500 feet; the total thickness of the British rocks from the Permian to the Tertiary inclusive, working out to about 12,500 feet. It is, however, very questionable whether such an aggregate thickness occurs in any one locality; while in the case of the older rocks, from the base of the Permian down to the base of the Cambrian, they are developed in great thickness in direct superposition.

Characteristics of the Folding of the Eastern and Western Areas of England and Wales contrasted.

The rocks already described as occupying the eastern half and south of England are characterised by long low folds breaking into sharp anticlinals and synclinals at a

few points only, such as in the Chalk at Flamborough Head and in the Tertiaries of the Isle of Wight, the eroded edges of these long folds forming the characteristic escarpments stretching across the country in a south westerly and north-easterly direction. Sharply contrasted with these long undulations are the strata forming the mountain nuclei of Wales and Cumberland, where we find the rocks sharply bent and compressed, the remnants of the primitive folds forming by denudation the mountain scenery as now beheld by us. Intermediately we find areas of the Carboniferous and Old Red having a horizontal development, such as is to be seen in the Carboniferous of the neighbourhood of Whernside and Ingleborough, and can be well studied near to Dent, where the much contorted Silurians are in juxtaposition to the less disturbed Carboniferous, the latter being let down by an enormous fault of unascertained throw. Again, in Herefordshire and South Wales we see a considerable extent of horizontal Old Red, which, as it approaches the Silurian mountain folds, becomes itself conformably inclined.

Not less interesting and instructive are the dome-like structures, such as the celebrated dissected Silurian dome of Woolhope, which rises in successive rings through the Old Red, which it carries on its flanks. May Hill is another similar structure, not so perfectly formed and also bisected by faulting against the Trias.

The physical constitution of Herefordshire and Brecknockshire is largely a horizontal plane of Old Red Sandstone, which, where it approaches the folded Silurian areas at the margins or round the enclosed domes, takes on the folds of the older rocks on which it lies.

Silurian and Old Red of the South-east of Scotland.

It will be instructive now to turn our attention to the rocks of a similar age to be seen dissected in the splendid line of cliffs from Berwick-on-Tweed to the far north of St. Abbs Head and Siccar Point. Here the Silurian (Lower Silurian) is intensely folded, and instead of the conformable succession from the Silurian, through the Old Red and Carboniferous which we have just seen obtains in Herefordshire and South Wales, we see the Upper Old Red Sandstone conglomerate resting upon the edges of the Lower Silurian in the strongest unconformity. Well may the justly celebrated Hutton have exhibited this phenomenon, as seen at Siccar Point, as one of the best illustrations of the views he developed in the "Theory of the Earth."

So perfectly are the two formations cemented together that it is possible to get hand specimens of the unconformity. It would appear that while the sediments of South Wales were being laid down in quiet waters from the beginning of the Upper Silurian to the close of the Carboniferous, the succession of events was several times broken in Scotland, as shown, not only by the strong unconformity already spoken of between the Upper Old Red and the Lower Silurian, which I have myself seen, but by the unconformity Sir Archibald Geikie shows exists between the Lower Old Red and the Lower Silurian,* and even between the Upper and Lower Old Red †; and he further states "that the great earth movements which plicated the Highlands and Southern Uplands were probably simultaneous, and took place

* "The Geology of Eastern Berwickshire": Memoirs of Geological Survey, p. 20. "Scenery and Geology of Scotland," second edition, p. 122, also p. 138.

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chiefly during the long series of ages represented by Upper Silurian deposits."* As the Upper Silurian in Lanarkshire passes gradually into the overlying Old Red Sandstone,† it is probable that the break between the Upper and Lower Silurian we have seen exists in England and Wales also extends to Scotland. The succession of events in the latter country are indeed more complex and difficult to trace than in South Britain, but it is sufficient for the present purpose simply to mention them as all pointing towards the immense range of geological time represented by the conformable Upper Silurian Old Red Sandstone and Carboniferous of South-west Britain.

Thickness and Extent of Rock Formations a measure of their plication.

The preceding sketch is little more than the barest outline of geological events recorded in the rocks of our own island, yet attentively studied the following facts stand out prominently:—The sedimentary rocks which were deposited in the greatest volume are those also that subsequently became most plicated. Though they were the earliest laid down, they even now constitute the distinctly mountain masses of Britain, and possess actually the highest peaks and the highest average elevation. When it is considered that these mountains have been exposed to the destroying agencies of denudation for an enormous period of geological time, and still stand pre-eminent above those built out of younger formations, we may perhaps picture to ourselves in some slight degree the extent of the original mass. Not only are the Cambrian and Silurian formations here of enormous thickness, but they are of surprising and unknown extent,

* *Ibid.* p. 290. † *Ibid.* p. 327.

By the aid of numerous geologists, both great and humble, of all climes and countries, manfully working towards a common end, the order of succession has been outlined, and a fair but very crude knowledge of the earth's history reached. So far as palæontology and stratigraphy can speak, they tell us a good deal, but we cannot realise the meaning of it all without the aid of correct physical conceptions to reveal the processes of the wonderful earth-history which lies buried under our feet.

It is with this object that I ask your indulgence this evening in mentally travelling with me over the British Isles to see what help we can get from known British geology.

Facts of British Geology.

An examination of a good geological map of England and Wales, such as that known as Greenough's, published by the Geological Society, shows at once that the older rocks from the Cambrian to the Carboniferous constitute the bulk of the more essentially mountain areas.

Thus, North Wales is mainly Cambrian and Silurian ; Cumberland and Westmoreland are largely composed of equivalent rocks, surrounded with a fringe of Carboniferous, which, more greatly developed in Northumberland, Durham, Yorkshire, and Derbyshire, forms the mountainous district of the Pennine Chain, the so-called backbone of Northern England. Leaving out of consideration for the moment the pre-Cambrian rocks of Anglesey and Shropshire, it is in the Cambrian and Silurian that the greatest deformations and foldings have taken place. Lying conformably upon the Upper Silurian in Herefordshire and Brecknockshire is the great thickness of Old Red Sandstone, more horizontally developed, but yet in the Beacons of Brecon and the Fans of Car-

ate to the original mass of the deposits out of which they have been fashioned by earth forces. If these facts stood alone they might be considered nothing more than curious coincidences. If, however, we cast our eyes abroad to the great continents we find that similar principles hold good, and that the mountain massives are related the world over to the thickness and volume of the deposits out of which they have been fashioned. Thus, the Alps, the mountains of the Caucasus, the Himalayas, are Tertiary structures; the Appalachians and Urals, Carboniferous; and these mountain chains are constructed of enormous thicknesses and volumes of sedimentary rocks.

Expansion and Contraction the cause of Folding and Faulting.

We may well ask ourselves why this relation between volume of sediment and greatness of disturbance should be so constant, and any theory of mountain genesis must necessarily explain these associated facts. The once favourite hypothesis which accounts for them by a shrinkage of the nucleus of the earth and the closing in of the non-shrinking crust upon it, and consequent folding by tangential pressure, fails to explain the constancy of the connection of great thicknesses of sedimentary rocks with the evolution of mountain ranges.

Neither does the principle of isostacy so insisted upon by American geologists explain the compression, folding, and building up of great masses of sediment into mountain ranges. On the principle of isostacy, it must be obvious to anyone possessing even a rudimentary acquaintance with mechanics that the sinking of the bed of the seas on which great deposits are accumulating, and to some extent a rise of surrounding land, may be explained, but not the lateral compression and elevation of the sediments themselves into mountain ranges.

It is thus seen that the western half of England, together with Wales, possess the mountainous districts *par excellence*, while the eastern half is distinguished by gently undulating or horizontal strata, with sharp folds located in small areas, as in the Isle of Wight, at Purbeck, and the Yorkshire Chalk at Flamborough Head.

That the Lias had formerly extended over a considerable area of the western half is shown by the preservation of outliers in Shropshire, Staffordshire, and Cumberland, and *prima facie* it is probable that the overlying formations have also at one time in geological history been present. To a student of physical geology a glance at the geological map of England is sufficient to show that the outcrop of the Lias extending from the Severn to the Tees is an escarpment of denudation.

It must not be supposed for a moment that Britain represents the normal physiographic condition of the various formations all over the world, and that the mountain areas are always the oldest. Quite the contrary. In the Alps, Himalayas, and Rockies, in the mountains of the Caucasus and Central Turkestan, it is the younger formations that constitute the highest members of the mountain belts, and it is generally conceded that the bulk of the mountain-making in these chains has been geologically a late event.

Of course in great mountain chains we may have, and generally do have, the older rocks, even to the Archean gneisses and schists thrown up and exposed in their axial folds. This, however, as a rule, only shows that the earth movements to which they owe their birth and growth have been extreme and profound, involving the deep-lying sediments, and even their foundation rocks, in the general movement. We thus see that there

through the shrinkage of the earth's nucleus provides for compression only. Contraction, by which I have shown that normal faults are produced, is not part of the machinery of any other theory than the one associated with my name.

I ask geologists to bring to the consideration of these great problems clearness of vision, for, usually, a single aspect only is examined, the rest being left in an impenetrable haze.

I trust I have now brought sufficient evidence before you to show that a broad examination of the formations of these islands, and their associated physical phenomena, throws a good deal of light on the problems of mountain-building, and that their remarkable relations are well worth more detailed examination than I have been able to give them in this address.

A CONTRIBUTION TO THE DYNAMICAL THEORY OF THE CRAVEN HIGHLANDS.

By the Rev. Fred. F. Grensted, Diocesan Inspector of Religious Education.

(*Read 12th November, 1895*).

It was my good fortune to spend some five weeks of the summers of 1894 and 1895 at two places which lie close to the great Craven system of faults. In 1894 I explored the country round Dent, in 1895 that round Horton-in-Ribblesdale, and in both visits I used to take as the constant companion of my walks the Ordnance Maps of the Geologic Survey of England and Wales.

The investigation of the origin of this stupendous system of faults, which has determined the character of the whole scenery of the district, presented itself to me

very little doubt that their areal extension was proportionately as great as their thickness. Between the Carboniferous and the Silurian there is a strong unconformity in the north of England and North Wales, but this is bridged over, as already explained, in Shropshire, Herefordshire, and South Wales, by the Old Red Sandstone, estimated at 10,000 feet. The Silurian shades upwards into the Old Red by well-defined passage beds, to be seen in many sections, while the Old Red graduates into the Carboniferous in a no less perfect manner.

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map 97, N.W., and to the east of south. I am, however, unacquainted personally with these portions of the fault, and the maps seem to show that other forces have been at work, which, I consider, mask those features that can be referred to the Bainbridge centre.

For these reasons I wish to confine my remarks to the tract of country contained within two lines drawn respectively west and south from Bainbridge, and specially to the Craven faults, as it there manifests itself.

Of this area, let it first be noted that the Carboniferous strata are practically horizontal, and that faults are few and insignificant, although such as there are, all lie nearly parallel to that circumference which may be drawn from Bainbridge as a centre. Let us next travel due west, and enter a district represented by sheet 98, S.E. Faults become larger and more frequent as we proceed, reaching a maximum at 17 miles west of Bainbridge, where we cross the Pennine fault; but they still continue to be important for many miles further, and all run from north to south as their average direction.

Next let us travel due south from Bainbridge into the district represented by sheet 92, N.W. Precisely the same phenomena are met with, except that the faults here under the name of the Craven run mainly east and west. In fact, all faults in this district are more or less tangential to circles drawn about Bainbridge as a centre. They are insignificant near Bainbridge, but are larger as we travel either west or south, and reach a maximum 17 miles away as we cross the Pennine or Craven systems.

As to the epoch at which these faults were formed, it must be remarked that some of them strike through

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Characteristics of the Folding of the Eastern and Western Areas of England and Wales contrasted.

The rocks already described as occupying the eastern half and south of England are characterised by long low folds breaking into sharp anticlinals and synclinals at a

the denuded surface of great Silurian folds. Horizontal sections of these same folds can be traced on the floor of the Ribblesdale Valley, and by combining the vertical with the horizontal sections we arrive at the real shape of the folds.

Connected with this remarkable coincidence of direction between fault and fold there is another peculiarity; it is along this same line that the oldest rocks of the series appear. Coniston limestone is found at the entrance to Dent Valley, at Ingleton, and, dipping under Maughton, across Ribblesdale.

Does this investigation enable us to review the history of the district as a connected whole? Surely, it does. First it comes before us as a depressed area, within which an enormous thickness of Silurian grit shale, and limestone is deposited. Then follows folding and upheaval; a long period succeeds, in which the surface is above water and subject to denudation, and as it is impossible to imagine the enormous folds on whose denuded tops the Carboniferous strata were deposited being formed near the surface, it is obvious that the period was a long one, commensurate with the enormous amount of denudation that then took place. It is to this period, that of denudation, that I attribute the first series of faults, the pre-carboniferous ones; and *pari passu* with their formation, the places where they reached the surface were planed level, ready in due time to receive the horizontal Carboniferous strata. The area next a second time recedes below the water, and the great Carboniferous series was deposited which is here unfolded, though the system of folds which belong to it can be found elsewhere. A second time does this area emerge, and with this second emergence a second series of faulting along the old line of weakness, now striking

Silurian and Old Red of the South-east of Scotland.

It will be instructive now to turn our attention to the rocks of a similar age to be seen dissected in the splendid line of cliffs from Berwick-on-Tweed to the far north of St. Abbs Head and Siccar Point. Here the Silurian (Lower Silurian) is intensely folded, and instead of the conformable succession from the Silurian, through the Old Red and Carboniferous which we have just seen obtains in Herefordshire and South Wales, we see the Upper Old Red Sandstone conglomerate resting upon the edges of the Lower Silurian in the strongest unconformity. Well may the justly celebrated Hutton have exhibited this phenomenon, as seen at Siccar Point, as one of the best illustrations of the views he developed in the "Theory of the Earth."

So perfectly are the two formations cemented together that it is possible to get hand specimens of the unconformity. It would appear that while the sediments of South Wales were being laid down in quiet waters from the beginning of the Upper Silurian to the close of the Carboniferous, the succession of events was several times broken in Scotland, as shown, not only by the strong unconformity already spoken of between the Upper Old Red and the Lower Silurian, which I have myself seen, but by the unconformity Sir Archibald Geikie shows exists between the Lower Old Red and the Lower Silurian,* and even between the Upper and Lower Old Red †; and he further states "that the great earth movements which plicated the Highlands and Southern Uplands were probably simultaneous, and took place

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Thickness and Extent of Rock Formations a measure of their plication.

The preceding sketch is little more than the barest outline of geological events recorded in the rocks of our own island, yet attentively studied the following facts stand out prominently:—The sedimentary rocks which were deposited in the greatest volume are those also that subsequently became most plicated. Though they were the earliest laid down, they even now constitute the distinctly mountain masses of Britain, and possess actually the highest peaks and the highest average elevation. When it is considered that these mountains have been exposed to the destroying agencies of denudation for an enormous period of geological time, and still stand pre-eminent above those built out of younger formations, we may perhaps picture to ourselves in some slight degree the extent of the original mass. Not only are the Cambrian and Silurian formations here of enormous thickness, but they are of surprising and unknown extent,

* *Ibid.* p. 299. † *Ibid.* p. 327.

and they are found whenever denudation has proceeded far enough to bare them to the eye.

Again, the Carboniferous, taken together with the Devonian and Old Red Sandstone, occupying the second place in the mountain structure of the British Isles, consist of great masses of sediment, not indeed rivalling the Silurian in volume, but of great extent and thickness, though much denuded. Some portions are considerably folded, and most are greatly faulted, but as a whole do not show anything like the signs of lateral compression which are seen in the Cambrian and Silurian.

The Permian and Triassic rocks come next in time and, curiously enough, in importance as regards thickness, and the country they occupy, if not mountainous, possesses a more faulted structure than any of the following formations, and is of a more hilly character.

When we ascend to the Lias, Oolites, and Cretaceous, then the beds become more continuous, horizontal, and less faulted. Folds, and sharp ones, are to be met with, but these, as a rule, are local, the lateral pressure to which they were subjected having been less, and concentrated at fewer points. The same peculiarities apply to the Tertiary rocks, perhaps in a stronger degree.

Relation of Orographic Structures to the mass of the sediment composing them.

I trust that I have now said sufficient to show that there is in the British Isles an intimate connection between the depth, extent, and mass of the several great deposits marking the progress of geologically recorded events, and the structures into which they have been severally raised.

The mountain-building and the foldings and the faultings are, roughly speaking, found to be proportion-

ate to the original mass of the deposits out of which they have been fashioned by earth forces. If these facts stood alone they might be considered nothing more than curious coincidences. If, however, we cast our eyes abroad to the great continents we find that similar principles hold good, and that the mountain massives are related the world over to the thickness and volume of the deposits out of which they have been fashioned. Thus, the Alps, the mountains of the Caucasus, the Himalayas, are Tertiary structures; the Appalachians and Urals, Carboniferous; and these mountain chains are constructed of enormous thicknesses and volumes of sedimentary rocks.

Expansion and Contraction the cause of Folding and Faulting.

We may well ask ourselves why this relation between volume of sediment and greatness of disturbance should be so constant, and any theory of mountain genesis must necessarily explain these associated facts. The once favourite hypothesis which accounts for them by a shrinkage of the nucleus of the earth and the closing in of the non-shrinking crust upon it, and consequent folding by tangential pressure, fails to explain the constancy of the connection of great thicknesses of sedimentary rocks with the evolution of mountain ranges.

Neither does the principle of isostacy so insisted upon by American geologists explain the compression, folding, and building up of great masses of sediment into mountain ranges. On the principle of isostacy, it must be obvious to anyone possessing even a rudimentary acquaintance with mechanics that the sinking of the bed of the seas on which great deposits are accumulating, and to some extent a rise of surrounding land, may be explained, but not the lateral compression and elevation of the sediments themselves into mountain ranges.

Where, then, are we to look for the agency constantly associated with the deposit of great volumes of sediment which is capable of eventually upheaving them from below the sea-level, and by lateral compression and folding throwing them into mountain chains?

Again, when after the lapse of lengthened periods of geological time, denudation has cut away and removed into the sea large masses of elevated land, what agency is it that causes it to shrink and become traversed by great lines of faulting?

It appears to me now, even more vividly than it has done in the past, that the only agency with which we are acquainted constantly associated with sedimentation and denudation, and capable of these enormous dynamical effects, is change of temperature: that expansion by increase of heat is the cause of the folding, compression, and upheaval of rocks, while loss of heat and consequent shrinkage is the cause of the earth fractures known as normal faults. This principle I explained fully in 1886 in my "Origin of Mountain Ranges"; since then the theory has been subjected to much criticism, ranging from a questioning of fundamental principles down to a minor examination of small details.

The fundamental position has, I maintain, not been shaken, either by mathematical physics or geological facts. The more the theory is tested by the light of practical geology the more remarkable is the explanation it affords of the associated phenomena of sedimentation and mountain-building; denudation and faulting. Furthermore, no other theory yet brought forward attempts to offer an explanation of more than one set of these phenomena, namely, those of compression. Normal faulting cannot be accounted for by compression, yet the rival theory of tangential pressure on the crust

through the shrinkage of the earth's nucleus provides for compression only. Contraction, by which I have shown that normal faults are produced, is not part of the machinery of any other theory than the one associated with my name.

I ask geologists to bring to the consideration of these great problems clearness of vision, for, usually, a single aspect only is examined, the rest being left in an impenetrable haze.

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The investigation of the origin of this stupendous system of faults, which has determined the character of the whole scenery of the district, presented itself to me

as a problem worthy of the fullest consideration, and by degrees I was led to interpret the natural features of the country in the manner which this paper brings before you.

The district consists of a Carboniferous Limestone plateau, bounded on the west and south by the Craven faults, and resting on highly-folded Silurian rocks, which are exposed in a few of the deeper valleys.

This seems to bring before us two widely-separated geologic epochs—the Silurian and the Carboniferous. The problem is to link these two epochs together, and to regard them rather as incidents in one continuous geologic process representing the history of the surface of the earth within that area, and then to form some conception of what that process has been, and how it has been caused. If we can succeed in this, it may reveal to us principles of universal application in Geology, and show us how the whole vertical distribution of matter on the globe has been caused, and hence how land and water come to be distributed as they are.

First, let us fix our attention on Bainbridge, a village east of Hawes in map, sheet 97, S.W. We are here in a district whose formation is wholly Carboniferous Limestone, a plateau in which the strata lie almost absolutely horizontal, where foldings are absent, and faults very rare and insignificant. This plateau has been denuded in every direction into deep valleys, leaving a few of the higher portions as hills capped by Millstone Grit.

Let us draw from Bainbridge a line due west 17 miles in length, and, treating it as the radius of a circle, draw the circumference until that radial line is due south. This portion of circumference will lie almost exactly on the Craven faults, and, indeed, it will do so to a certain extent both to the north of west, as we see on

map 97, N.W., and to the east of south. I am, however, unacquainted personally with these portions of the fault, and the maps seem to show that other forces have been at work, which, I consider, mask those features that can be referred to the Bainbridge centre.

For these reasons I wish to confine my remarks to the tract of country contained within two lines drawn respectively west and south from Bainbridge, and specially to the Craven faults, as it there manifests itself.

Of this area, let it first be noted that the Carboniferous strata are practically horizontal, and that faults are few and insignificant, although such as there are, all lie nearly parallel to that circumference which may be drawn from Bainbridge as a centre. Let us next travel due west, and enter a district represented by sheet 98, S.E. Faults become larger and more frequent as we proceed, reaching a maximum at 17 miles west of Bainbridge, where we cross the Pennine fault; but they still continue to be important for many miles further, and all run from north to south as their average direction.

Next let us travel due south from Bainbridge into the district represented by sheet 92, N.W. Precisely the same phenomena are met with, except that the faults here under the name of the Craven run mainly east and west. In fact, all faults in this district are more or less tangential to circles drawn about Bainbridge as a centre. They are insignificant near Bainbridge, but are larger as we travel either west or south, and reach a maximum 17 miles away as we cross the Pennine or Craven systems.

As to the epoch at which these faults were formed, it must be remarked that some of them strike through

both Carboniferous and Silurian, and must be, therefore, of post-Carboniferous age; whilst others dislocate the Silurian, but are capped with unfaulted Carboniferous. The latter must, therefore, have preceded the denudation of the Silurian upon which the Carboniferous was subsequently deposited.

The only possible conclusion from these facts is, that there has been a common cause acting throughout such geologic time as embraces the Carboniferous and Silurian epochs, in such a way as to cause faults whose directions are tangents drawn to circles which have Bainbridge as a centre. This is, surely, a very important consideration when we try to look at the geology of the district as a connected whole.

We will next leave the faults and refer to the folds. Within this area the Carboniferous strata are practically undisturbed, in strong contrast to the Silurian, which are highly contorted. It is a remarkable fact that, wherever investigation is possible, he folds in the Silurian are found to be long, cigar-shaped undulations, blending with one another, and again lying parallel to the Craven faults, or tangential to the Bainbridge centre circles. The main places where this can be studied are, imperfectly, due west at the entrance to the Dent Valley; completely, south-west up the Ingleton Valley; south in the neighbourhood of Wharf and Austwick; and up the Ribblesdale Valley. All this can be traced in the Ordnance Survey Maps, but the finest exposure is to be found on the sides of Maughton. This is a spur of Carboniferous rock extending southwards, and forming the west side of Ribblesdale. On both sides of this spur, but especially on its western face, there are sections exposed some hundreds of feet in vertical height, where we see perfectly horizontal Carboniferous strata lying on

the denuded surface of great Silurian folds. Horizontal sections of these same folds can be traced on the floor of the Ribblesdale Valley, and by combining the vertical with the horizontal sections we arrive at the real shape of the folds.

Connected with this remarkable coincidence of direction between fault and fold there is another peculiarity; it is along this same line that the oldest rocks of the series appear. Coniston limestone is found at the entrance to Dent Valley, at Ingleton, and, dipping under Maughton, across Ribblesdale.

Does this investigation enable us to review the history of the district as a connected whole? Surely, it does. First it comes before us as a depressed area, within which an enormous thickness of Silurian grit shale, and limestone is deposited. Then follows folding and upheaval; a long period succeeds, in which the surface is above water and subject to denudation, and as it is impossible to imagine the enormous folds on whose denuded tops the Carboniferous strata were deposited being formed near the surface, it is obvious that the period was a long one, commensurate with the enormous amount of denudation that then took place. It is to this period, that of denudation, that I attribute the first series of faults, the pre-carboniferous ones; and *pari passu* with their formation, the places where they reached the surface were planed level, ready in due time to receive the horizontal Carboniferous strata. The area next a second time recedes below the water, and the great Carboniferous series was deposited which is here unfolded, though the system of folds which belong to it can be found elsewhere. A second time does this area emerge, and with this second emergence a second series of faulting along the old line of weakness, now striking

both through Carboniferous and Silurian, has occurred. It is a remarkable fact that in each case—at each epoch—the folded rocks, which were presumably the ones specially concerned with local upheaval, were also the ones subsequently to specially fall in. At the earlier epoch the Silurians within what is now Pennine and Craven fault; at the later epoch the Carboniferous outside it. Between these two subsidences we find the remains of that rim I have above indicated as marked by the occurrence of Coniston limestone.

Finally, what is the one common cause which underlies all these earth movements as surely as they can be geometrically referred to that common centre, Bainbridge? When we speak of causes we enter the realms of theories; but do these facts lend the faintest support to that theory of mountain building which assumes that our planet, shrinking in its old age, finds its former envelope of cooled crust too large, and, therefore, is compelled to wrinkle it? If that be the cause, it must act in a continuous and cumulative manner; but here we find action within a limited area which has alternated depression and deposition with upheaval and denudation—contortion with faulting. How could a cause acting continuously have given this alternating result? I cannot see that it could. I believe these results are entirely in accord with the theory first enunciated by your President, Mr. T. M. Reade, in his "Origin of Mountain Ranges." Deposition was necessarily followed by the raising of temperature. As that deposit caused the former surface of the earth to be deeply buried in its interior, the store of slowly radiating central heat thus locally retained caused local expansion, and this expressed itself still more locally in folds and upheavals. Then came the alternation—denudation succeeded to deposition—and,

therefore, because this caused the temperature to fall, it also caused contraction as expressed by faulting to succeed to expansion as expressed by folding. Contraction involves subsidence, and subsidence stops denudation, for, as the land disappears below the waters, the action is reversed and succeeded by deposition. In this way alone can I understand that curious reversal of action which seems to have twice taken place within this area.

OBSERVATIONS ON GLACIAL STRIÆ.

By Joseph Lomas, A.R.C.S.,
Special Lecturer on Geology, University College, Liverpool.

(Read 12th November, 1895).

In and about Liverpool there have been recorded a great number of cases where striæ occur on the bed rock. Within a very moderate area we have more than forty examples. Some of them are very extensive, and must be measured in thousands of square yards.

Opinion has been, and is, largely divided as to the agent which produced the groovings and striations. Some attribute them to floating ice. They base their opinions largely on the fact that the striæ are not uniformly parallel over the district, and so must have been formed by stranded icebergs which were at the mercy of the tides. Others maintain that ice in the form of a glacier is competent to produce all the effects seen, and variations in direction must be set down to local thrusts in the ice caused by the character of the ground. A third view invokes the presence of both agencies at different times, and points to effects produced by both floating and land ice.

and they are found whenever denudation has proceeded far enough to bare them to the eye.

Again, the Carboniferous, taken together with the Devonian and Old Red Sandstone, occupying the second place in the mountain structure of the British Isles, consist of great masses of sediment, not indeed rivalling the Silurian in volume, but of great extent and thickness, though much denuded. Some portions are considerably folded, and most are greatly faulted, but as a whole do not show anything like the signs of lateral compression which are seen in the Cambrian and Silurian.

The Permian and Triassic rocks come next in time and, curiously enough, in importance as regards thickness, and the country they occupy, if not mountainous, possesses a more faulted structure than any of the following formations, and is of a more hilly character.

When we ascend to the Lias, Oolites, and Cretaceous, then the beds become more continuous, horizontal, and less faulted. Folds, and sharp ones, are to be met with, but these, as a rule, are local, the lateral pressure to which they were subjected having been less, and concentrated at fewer points. The same peculiarities apply to the Tertiary rocks, perhaps in a stronger degree.

Relation of Orographic Structures to the mass of the sediment composing them.

I trust that I have now said sufficient to show that there is in the British Isles an intimate connection between the depth, extent, and mass of the several great deposits marking the progress of geologically recorded events, and the structures into which they have been severally raised.

The mountain-building and the foldings and the faultings are, roughly speaking, found to be proportion-

ate to the original mass of the deposits out of which they have been fashioned by earth forces. If these facts stood alone they might be considered nothing more than curious coincidences. If, however, we cast our eyes abroad to the great continents we find that similar principles hold good, and that the mountain massives are related the world over to the thickness and volume of the deposits out of which they have been fashioned. Thus, the Alps, the mountains of the Caucasus, the Himalayas, are Tertiary structures; the Appalachians and Urals, Carboniferous; and these mountain chains are constructed of enormous thicknesses and volumes of sedimentary rocks.

Expansion and Contraction the cause of Folding and Faulting.

We may well ask ourselves why this relation between volume of sediment and greatness of disturbance should be so constant, and any theory of mountain genesis must necessarily explain these associated facts. The once favourite hypothesis which accounts for them by a shrinkage of the nucleus of the earth and the closing in of the non-shrinking crust upon it, and consequent folding by tangential pressure, fails to explain the constancy of the connection of great thicknesses of sedimentary rocks with the evolution of mountain ranges.

Neither does the principle of isostacy so insisted upon by American geologists explain the compression, folding, and building up of great masses of sediment into mountain ranges. On the principle of isostacy, it must be obvious to anyone possessing even a rudimentary acquaintance with mechanics that the sinking of the bed of the seas on which great deposits are accumulating, and to some extent a rise of surrounding land, may be explained, but not the lateral compression and elevation of the sediments themselves into mountain ranges.

Where, then, are we to look for the agency constantly associated with the deposit of great volumes of sediment which is capable of eventually upheaving them from below the sea-level, and by lateral compression and folding throwing them into mountain chains?

Again, when after the lapse of lengthened periods of geological time, denudation has cut away and removed into the sea large masses of elevated land, what agency is it that causes it to shrink and become traversed by great lines of faulting?

It appears to me now, even more vividly than it has done in the past, that the only agency with which we are acquainted constantly associated with sedimentation and denudation, and capable of these enormous dynamical effects, is change of temperature: that expansion by increase of heat is the cause of the folding, compression, and upheaval of rocks, while loss of heat and consequent shrinkage is the cause of the earth fractures known as normal faults. This principle I explained fully in 1886 in my "Origin of Mountain Ranges"; since then the theory has been subjected to much criticism, ranging from a questioning of fundamental principles down to a minor examination of small details.

The fundamental position has, I maintain, not been shaken, either by mathematical physics or geological facts. The more the theory is tested by the light of practical geology the more remarkable is the explanation it affords of the associated phenomena of sedimentation and mountain-building; denudation and faulting. Furthermore, no other theory yet brought forward attempts to offer an explanation of more than one set of these phenomena, namely, those of compression. Normal faulting cannot be accounted for by compression, yet the rival theory of tangential pressure on the crust

through the shrinkage of the earth's nucleus provides for compression only. Contraction, by which I have shown that normal faults are produced, is not part of the machinery of any other theory than the one associated with my name.

I ask geologists to bring to the consideration of these great problems clearness of vision, for, usually, a single aspect only is examined, the rest being left in an impenetrable haze.

I trust I have now brought sufficient evidence before you to show that a broad examination of the formations of these islands, and their associated physical phenomena, throws a good deal of light on the problems of mountain-building, and that their remarkable relations are well worth more detailed examination than I have been able to give them in this address.

A CONTRIBUTION TO THE DYNAMICAL THEORY OF THE CRAVEN HIGHLANDS.

By the Rev. Fred. F. Grensted, Diocesan Inspector of Religious Education.

(Read 12th November, 1895).

It was my good fortune to spend some five weeks of the summers of 1894 and 1895 at two places which lie close to the great Craven system of faults. In 1894 I explored the country round Dent, in 1895 that round Horton-in-Ribblesdale, and in both visits I used to take as the constant companion of my walks the Ordnance Maps of the Geologic Survey of England and Wales.

The investigation of the origin of this stupendous system of faults, which has determined the character of the whole scenery of the district, presented itself to me

as a problem worthy of the fullest consideration, and by degrees I was led to interpret the natural features of the country in the manner which this paper brings before you.

The district consists of a Carboniferous Limestone plateau, bounded on the west and south by the Craven faults, and resting on highly-folded Silurian rocks, which are exposed in a few of the deeper valleys.

This seems to bring before us two widely-separated geologic epochs—the Silurian and the Carboniferous. The problem is to link these two epochs together, and to regard them rather as incidents in one continuous geologic process representing the history of the surface of the earth within that area, and then to form some conception of what that process has been, and how it has been caused. If we can succeed in this, it may reveal to us principles of universal application in Geology, and show us how the whole vertical distribution of matter on the globe has been caused, and hence how land and water come to be distributed as they are.

First, let us fix our attention on Bainbridge, a village east of Hawes in map, sheet 97, S.W. We are here in a district whose formation is wholly Carboniferous Limestone, a plateau in which the strata lie almost absolutely horizontal, where foldings are absent, and faults very rare and insignificant. This plateau has been denuded in every direction into deep valleys, leaving a few of the higher portions as hills capped by Millstone Grit.

Let us draw from Bainbridge a line due west 17 miles in length, and, treating it as the radius of a circle, draw the circumference until that radial line is due south. This portion of circumference will lie almost exactly on the Craven faults, and, indeed, it will do so to a certain extent both to the north of west, as we see on

map 97, N.W., and to the east of south. I am, however, unacquainted personally with these portions of the fault, and the maps seem to show that other forces have been at work, which, I consider, mask those features that can be referred to the Bainbridge centre.

For these reasons I wish to confine my remarks to the tract of country contained within two lines drawn respectively west and south from Bainbridge, and specially to the Craven faults, as it there manifests itself.

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As to the epoch at which these faults were formed, it must be remarked that some of them strike through

depressula occurs in such great profusion. I was glad to find *Lagena fimbriata* var Danica in No. 2. I have also a specimen of the same thing from Glacial Clay, Newtownards. These are the first records of its having been found in Britain. Only a few months ago it was figured and described for the first time by Dr. Madsen, who obtained it from Glacial Clays in Denmark."

The following is Mr. Wright's detailed report :—

No. 1 (Glacial Clay).—2 lbs. 10 ozs. weight. After washing, 8 ozs. fine, 1 oz. coarse. The greater portion of the stones more or less rounded. Foraminifera plentiful.

FORAMINIFERA.

Miliolina tenuis (Czjzek), very rare.
Textularia globulosa (Ehr.), very rare.
Bulimina pupoides (d'Orb.), rare.
,, *marginata* (d'Orb.), very rare.
,, *fusiformis* (Will.), very rare.
Bolivina punctata (d'Orb.), rare.
,, *plicata* (d'Orb.), frequent.
,, *dilatata* (Rss.), rare.
Cassidulina lævigata (d'Orb.), rare.
,, *crassa* (d'Orb.), frequent.
Lagena globosa (Mont.), very rare.
,, *lineata* (Will.), very rare.
Lagena sulcata (W. & J.), very rare.
,, *hexagona* (Will.), very rare.
,, *lævigata* (Rss.), very rare.
Uvigerina angulosa (Will.), rare.
Globigerina bulloides (d'Orb.), common.
Discorbina rosacea (d'Orb.), very rare.
Truncatulina lobatula (W. & J.), rare.
Nonionina depressula (W. & J.), most abundant.
Polystomella striatopunctata (F. & M.), very rare.

About 400 specimens of *Nonionina depressula* were obtained from this gathering, whilst the other 20 species numbered in all only 63.

No. 2 (Glacial Clay). 3 lbs. weight. After washing, 10 oz. fine, 1 oz. coarse; the greater portion of the stones more or less rounded. Foraminifera plentiful.

FORAMINIFERA.

Miliolina tenuis (Czjzek), common.
Textularia globulosa (Ehr.), very rare.
Bulimina pupoides (D'Orb.), rare.
,, *fusiformis* (Will.), frequent.
Virgulina Schreibersiana (Czjzek), very rare.
Bolivina punctata (d'Orb.), rare.
,, *plicata* (d'Orb.), very common.
,, *dilatata* (Rss.), common.
Cassidulina crassa (d'Orb.), very common.
Lagena lævis (Mont.), rare.
,, *costata* (Will.), very rare.
,, *Williamsoni* (Alcock), frequent.
,, *lævigata* (Rss.), rare.
,, *lucida* (Will.), rare.
Lagena squamosa (Mont.), very rare.
,, *orbignyana* (Seg.), very rare.
,, *fimbriata* (var. Danica, Madsen), rare.
Uvigerina canariensis (d'Orb.), very rare.
,, *angulosa* (Will.), frequent.
Orbulina universa (d'Orb.), very rare.
Globigerina bulloides (d'Orb.), very common.
Discorbina globularis (d'Orb.), very rare.
,, *rosacea* (d'Orb.), rare.
,, *Bertheloti* (d'Orb.), very rare.
Pulvinulina Karsteni (Rss.), very rare.
Truncatulina lobatula (W. & J.), rare.
Rotalia Biccarii (var lucida, Madsen ?), rare.

Nonionina depressula (W. & J.), most abundant.
Polystomella striatopunctata (F. & M.), rare.

About 900 specimens of *Nonionina depressula* were obtained from this gathering, whilst the remaining 28 species numbered in all only 180.

To give an idea of the profusion of the Foraminifera in the clay examined, I may point out that they occur at the rate of over half a million individuals to the ton.

For the purpose of comparison, I append the list of Foraminifera found in a specimen of what is known as the Lower Boulder Clay of the Blackpool Cliffs, taken on the excursion of our Society to Blackpool, 26th August, 1895. I am also indebted to Mr. Joseph Wright for this examination.

Weight of clay, 16 oz. 5 Troy.

After washing, fine 5 oz., coarse 8 oz., stones rounded, one broken Turritella. Foraminifera plentiful.

	No. of Specimens.
Miliolina subrotunda (Mont.), very rare	1
Textularia globulosa (Ehr.), very rare	1
Bolivina plicata (d'Orb.), very rare..	1
Cassidulina crassa (d'Orb), frequent	8
Lagena lævigata (Rss.), very rare	1
Uvigerina angulosa (Will.), rare	3
Globigerina bulloides (d'Orb.), frequent	12
,, *cretacea* (d'Orb.), rare	2
Discorbina rosacea (d'Orb.), very rare	1
,, *globularis* (d'Orb.), very rare	1
Nonionina depressula (W. & J.), very common, about	150

AN ATTEMPT TO CLASSIFY THE FOOTPRINTS IN THE NEW RED SANDSTONE OF THIS DISTRICT.

By Henry C. Beasley.

(*Read 10th December, 1895.*)

From 1828, when footprints found in the New Red Sandstone of Annandale were described (though they had been found, I believe, in 1812 or 1813,) down to about thirty years ago, records of similar discoveries in the New Red Sandstone of other localities and speculations as to the animals that produced them are frequent in the proceedings of various societies. Since then, though not actually absent, such papers have been by no means numerous.

In the meanwhile our knowledge of Palæontology, particularly as regards reptilia, has been very largely increased. It was probably a feeling of the want of information in this respect that, although not expressed, led to a temporary decrease of work in this direction. With the increased material that has been placed in the hands of Palæontologists within the last two decades, I think the time ought to be approaching when it will be advisable to again give some attention to the only mesozoic organic remains in our district.

Without more training in anatomy, and more particularly in osteology, than is possessed by the ordinary geologist, we cannot hope to arrive at any definite conclusion as to the animals that made the footprints, and I certainly shall not attempt anything of the sort in this paper; but I trust we may do some useful work in collecting, and classifying if possible, the different types that have been noticed, clearing the ground and arranging the material ready for the specialist, and in noting any

points with regard to each type that seem worth record for further investigation.

The most comprehensive account of what has been hitherto done is to be found in a History of Ichnology ("Etude Ichnologique sur les Empreintes de pas des Animaux Fossiles") by Dr. T. C. Winkler, and published in the Memoirs of the Musée Teyler, Haarlem.* It gives accounts and descriptions of the footprints observed principally in the New Red Sandstone, in some sixty-four localities, with full references and very copious abstracts of the papers in which they are mentioned, occupying some 200 pages large 8vo., followed by about 18 pages of description and 12 plates of specimens, mostly from Hessburg, in the museum of the institution; and to that work I must acknowledge my great indebtedness. I have, however, where possible, referred to the original papers. There is one paper of some importance which has not been included, and that is an account of some footprints from a quarry at Weston Point, Runcorn, read before the Geological Society of London, November, 1845, by Dr. Black,† whose son, Surgeon-Major W. G. Black, has been a visitor at our meetings, and presented us with the photographs of Vesuvius that hang in this room. I would also refer to a paper by our member, Mr. O. W. Jeffs, recently read before the Geological Association of Liverpool, where he describes and figures a number of specimens in his own extensive collection.‡

*Archives of the Musée Teyler, Haarlem, 2nd Series, vol. ii., pt. 4. 1886.

† Observations on a Slab of New Red Sandstone from the Quarries at Weston, near Runcorn, Cheshire, containing impressions of footprints and other markings, by J. Black, M.D., F.G.S. Q.J.G.S., vol. ii., p. 65.

‡ Notes on a Series of Fossil Footprints from Storeton, in Cheshire. Journal of Liverpool Geological Association, vol. xiv. 1893-4.

With regard to investigations outside the district, I would refer to a paper by Mr. Geo. Varty Smith, F.G.S., Footprints of Vertebrate Animals, from the lower New Red Sandstone of Penrith. Q.J.G.S., vol. xl., p. 479.

My object in the present paper will be to endeavour to arrange temporarily the various footprints I have met with from Cheshire and Lancashire in groups to facilitate reference, and to draw attention to sundry points that I have not seen noticed, or to which attention does not seem to have been sufficiently drawn by other observers. After seeing a large number of slabs from various localities, there would, at first sight, appear to be an infinite diversity; but it will be seen that much of this seeming diversity does not arise from a different form of foot, but from the way in which it was put down or withdrawn, and from the different consistency of the material in which it was made.

Conditions.

It will be well to say a word here on the conditions under which these traces of a Triassic fauna have been preserved.

The idea that most readily occurs is that they were made on a seashore between tide marks, where the returning tide covered them by a fresh deposit. This theory is, however, not satisfactory, I., because there is some reason for believing that the Keuper beds were laid down in enclosed waters, whether salt lakes or inland seas, which would be unaffected by the tides.

II.—The marls in which many of them were made are intersected by desiccation cracks, very often extending completely through beds now having a thickness of over six inches, and probably, before being subjected to the pressure of the rock now covering them they were of greater thickness.

III.—Had they been covered by a current of water having sufficient velocity to carry sand to cover them, the sharpness of definition often observed would have been destroyed where they were made in mud. And

moreover they are often found in a bed of sandstone—presumably wet sand when they were formed—and under the fore-mentioned circumstances would undoubtedly have been entirely eroded.

IV.—We find these beds of marl had a very strongly-marked concave surface between the cracks, in fact were more or less curled up. The facts recorded in the paper of Messrs. Reade and Davies, read last Session, prove that this curved surface would not be preserved after they were covered by water.*

The conclusion to which I have come is that they were covered by wind-blown sand.

GROUPING.—GROUP A.

I have given figures of the types of several groups into which I propose to classify the footprints, and the one to which attention is naturally first drawn is that of the hand-shaped type, known as Cheirotherium. I know that there is a strong feeling in favour of its being termed Cheirosaurus, because the former term appeared to presuppose its being the footprint of a mammal; but the alternative presupposes it to be that of a saurian—certainly a more likely supposition, but at present not proved to be the case. I shall therefore adhere in this paper to the first name, Cheirotherium.

Although the neighbouring quarry of Storeton has been very prolific in these footprints, they were first described as occurring at Hessburg, near Hillburghausen, in sandstone, said to be Bunter. The first recorded observation was by M. C. Barth in 1833, and they were

* Proc. Liverpool Geol. Soc., vol. vii., p. 329. Since this paper was read my attention has been drawn to one by Prof. T. M'Kenny Hughes, F.G.S., "On some Tracks of Terrestrial and Fresh Water Animals," Q.J.G.S., vol. xl., p. 178, read 21st November, 1883, in which he gives the result of his own observation of recent tracks.

described by Dr. K. F. L. Sickler in 1834, and excited considerable interest at the time, and were generally supposed to be made by some mammal. Alex. von Humboldt read a note upon them in 1835 before the Academie des Sciences de Paris, and in it he weighs the claims of the various animals to which they had been assigned, rather favouring the idea of a marsupial origin, adding that they were not of reptilian origin as far as he could judge from his acquaintance with the tracks and mode of progression of the crocodiles of the Oronocco.

In 1838 footprints of the same character were found at Storeton by Mr. John Cunningham, F.G.S., and were described to the Natural History Society in this building. The Society appointed a committee to assist him in investigating the matter. The Society did not publish any proceedings, but lithographs of the footprints were made, and the report of the committee was read before the Geological Society of London, 5th December, 1838, and published in its Proceedings.*

Footprints of the Cheirotherium have also been found at Weston, Lymm, Tarporley, and Daresbury. There is a figure of a footprint from the latter quarry in the Q.J.G.S., vol. xxiii., 1867, showing the rough surface of the integument. The same is also to be noticed on one from Storeton in my collection. It was from Tarporley that Sir P. de Grey Egerton obtained the large form 15 inches in length, and named by him *C. Herculis*.

Prof. Owen showed satisfactorily by a process of reasoning that must claim the admiration of all, whether they agree with his conclusions or not, that these footprints were in all probability those of a Labyrinthodon, and without further reference to the facts that have come to light since Owen published his

* Proceedings, Geological Society of London, vol. iii., p. 12.

"Palæontology," text books have gone on repeating his opinion as a fact, and not only so, but have in many cases figured the labyrinthodon as an impossible, toad-like animal, in the act of making the footprints. However, since the date (1860) of Owen's "Palæontology," later researches—notably by Dr. Anton Fritsch and Prof. Miall—have given us a very full knowledge of the labyrinthodon, and in the reports of Prof. Miall to the British Association for 1873–4 he strongly combats the view of Owen, and has shown, I think conclusively, that, though agreeing well enough with the material at his disposal at the time, it will not hold good now. He points out that Owen's results in a great measure depended on two suppositions—I., that the bones found at a little distance from each other belonged to the same individual, and that (II.), an individual of the same species made the footprints found in the same beds; which, though at the time there was every reason to esteem them at least highly probable, would not weigh, in Prof. Miall's opinion, against other facts that have since come to light. Prof. Miall says that the footprints are more probably Dinosaurian than Amphibian, and this view I understand he upheld in a discussion on a paper by Prof. Marsh at the Ipswich meeting of the British Association.

The description of these footprints is given as follows by Mr. Lydekker in his catalogue of fossil reptilia and amphibia in the British Museum:—

"CHIROSAURUS.

"SYN: CHIROTHERIUM.

"The impressions of both feet are pentadactylate, "with distinct nails; those of the manus being rather "more than half the size of those of the pes. The pollex "is short and projects nearly at right angles to the

"axis of the third digit. The third digit of the pes is "the largest."

In a communication to this Society by Mr. G. H. Morton, March 7th, 1863, he suggested that, as Mr. Cunningham had not given any specific name to the footprints from Storeton, the name Storetonense should be used, to distinguish them from C. Barthii, C. Kaupii, and C. Herculis, from which they differ somewhat, and this suggestion has been generally accepted.

The best collection of specimens showing the feet in regular series is that at the Bootle Museum, formerly in the Royal Institution (photographs of these, shown by the aid of a lantern, were used to illustrate this paper), and on these the following remarks are mainly based.

One or two points I should like to draw attention to. In the first place Mr. Lydekker mentions the presence of nails, and I think there can be no doubt of his correctness, although I have often heard it stated that they were absent, and that this pointed to a batrachian origin. I have myself seen a Triton Cristata, which has no nails, produce a semblance of nails in its footprint by the manner in which it withdrew its foot from the clay in which it walked; but the feature is so constant in C. Storetonense, that there can be no doubt as to the presence of nails. We must remember that we are looking at the sole of the foot, and therefore see the impression of the worn under side of the nail.

Mr. Cunningham, in the report mentioned above, says:—"The animal must have crossed its feet 3 inches "in walking, for the right fore and hind feet are 1½ inch "to the left of the medial line, and the left fore and hind "feet 1½ inch to the right of the same line." A reference to one of the slabs at Bootle, which was probably one of those he had before him at the time, shows the accuracy

of his observation, supposing, as he evidently did, that the so-called "thumb" was the inner or first digit. Owen, however, speaks of it as a modified form of the fifth or outer digit. This is a very interesting point, but if fully entered into here would extend this paper to an undue length. The fact, however, in either case remains evident that the feet on both the right and left sides were placed on the ground almost in a straight line under the long axis of the animal's body.* One more point: the outline of the hind foot between the proximal end of the toes, which were protected apparently by a hardened pad, and the "thumb" is very imperfectly defined and often absent; but "the ball of the thumb" is generally pretty strongly marked, and the weight of the animal appears to have rested mainly on the toes of the pes. The manus did not usually leave such a strongly marked impression as the pes, the latter being often clearly shown when the former is hardly discernible, or even absent. When, however, clearly defined, it is seen that the toes are shorter in proportion and more evenly extended than those of the pes.

I have placed the Cheirotherium footprints in a group by themselves, which I shall call "A."

GROUP B.

In the next Group, B, I propose to include footprints somewhat resembling those of Group A, but considerably smaller, varying from three-quarters of an inch to two inches in length, whilst the Cheirotherium prints average seven to nine inches in length.

The foot was pentadactylate and palmate, the digits somewhat more parallel to each other and to the axis of the body, the fifth digit, corresponding to the "thumb"

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* See also "R. Owen on a Species of Labyrinthodon from Warwickshire." Trans. Geological Society, 2nd Series, vol. vii., page 536 (24th Feb., 1841).

of Cheirotherium, not distinctly curved, generally quite straight, but pointing somewhat outwards; the first digit short and pointing somewhat inwards; III. and IV. the longest and about the same length, II. being rather shorter. The whole outline of the foot is more distinctly marked than in the Cheirotherium. There are some indications of the presence of nails, but not of so decided a character as in Group A.

There is in the Bootle Museum a slab with five pentadactylate footprints in relief, in two rows. The prints are all very similar, apparently made by the right and left pes, with no print indicating the manus. The length of stride from heel to heel is 13 inches, the width of track 5½ inches, the right foot coming down opposite a point mid-way between two impressions of the left. There is a slightly sinuous track along the medial line, suggestive of the presence of a tail. The arrangement of the prints might suggest the bipedal progression of a rather broad-bodied animal, and bearing in mind Prof. Miall's suggestion of a Dinosaur in the case of the Cheirotherium, such an explanation would be very interesting if it were to prove the correct one. There is, however, the probability that the print of the hind foot coincided with that of the manus, and obliterated it. The tracks on the slab are not sufficiently clearly defined to say this is not the case. This was the view taken by Mr. Cunningham, who describes the slab in Vol. I. of Proceedings Lit. and Phil. Society, and figures one of the impressions thereon. He says it was found in cutting a road through Flaybrick Hill. There is no date to the description, which appears as an appendix describing the plates at the end of the volume.

The locality, "a road cutting through Flaybrick Hill," would point to their being found nearer the base

of the Keuper than footprints are usually found; but so much rock has been removed from Flaybrick Hill, that it is now difficult to speak positively on that point.

Another print bearing some resemblance to this, though much smaller—about 1¼ inches long—I found on a slab from the older part of the South Quarry at Storeton. The "thumb" is situated quite as far back, proportionately, as in the Cheirotherium, but it is not curved. Diligent search over the whole slab was made, to discover any others associated with it that could form a continuous track, but without success, which illustrates the very capricious manner in which these footprints are preserved. In the Flaybrick Hill slab the breadth of the track leaves no doubt as to the digit most nearly corresponding to the "thumb" of the Chirotherium being the fifth, or outer one. It seems always to have its origin farther back than the other digits.

In the sandstone of Upper Keuper age at Moorhey, Great Crosby, I found a single footprint of this type, and, though only four digits were distinctly marked, it bears a strong resemblance to the small one above described from Storeton.

I have also on several occasions seen a pentadactylate footprint, characterised by very straight digits, maintaining the same breadth throughout. I am inclined to think its peculiarities may be due to the conditions of its production rather than to the form of the foot, and I therefore at present include it in this group.

Group C.

Another form of pentadactylate footprint, distinguished by being of much greater proportional breadth, I would place in a third group, C. It is smaller than those just described, being about ¾ in. long by ⅝ in. broad. The length of the longer digits—viz., second,

third, and fourth—is not much more than twice their breadth. The first and fifth, being much shorter, are broader in proportion, and one—probably the first—is set much farther back than the rest. Possibly this may turn out to be the manus corresponding to a pes included in another group, but at present I have not been able to find it in a series.

We have, then, three groups of pentadactylate palmate footprints:—

"A."—Cheirotherium, 7 to 9 in. long, in form resembling a very fleshy human hand, with a remarkably strongly curved thumb.

"B."—A small footprint about 2 in. long, somewhat similar to A, but all the digits straight.

"C."—A short broad footprint about ½ to ¾ in. long.

GROUP D.

Perhaps the most common form of footprint in the Trias is that of three somewhat slender digits, with a fourth much shorter, and sometimes a trace of a very slender one on the opposite side from the short one. This is usually attributed to the Rhynchosaurus, and I shall take it as the type of my next group, "D." The palmar portion, where shown, is very short in proportion to the digits. The print consists almost entirely of the digits, and cannot be considered as palmate. The digits are generally more or less curved, and generally the nails in which they terminate are bent to one side. The form of the foot corresponds pretty closely to the skeleton of the hind foot as figured by Prof. Huxley.* This corresponds almost exactly with a footprint from Oxton, of which I give an outline, Plate I., D. 3. Prof. Owen first described the Rhynchosaurus remains found

* Q J.G.S., vol. xliii., p. 675, plate 27, fig. 5.—"Ventral aspect of right pes of Rhynchosaurus."

at Grimshill in the Trans. Cambridge Philos. Society,* but I have unfortunately been unable to refer to it. However, in his "Palæontology" (1st Edition), p. 240, he gives a description, and mentions the probability of the footprints found there being those of the same animal. I was unable to identify the original slab in the Shrewsbury Museum, but one brought there from Grimshill quite recently is covered with prints of the same type I have described. I could not trace any consecutive series, nor any that I could identify as those of the manus, although the slab has a square yard of surface covered with some hundreds of prints from 1 to 1 in. in length.

Prof. Huxley's figure of the skeleton of the manus on the plate referred to above would represent a very slender foot, and it is possible that the print of some very slender digits occasionally met with may represent the manus corresponding to the pes; but so far I have not traced its association with it (Plate I., D. 5). On the other hand, there is among the Rhynchosaurus remains at Shrewsbury a fairly perfect pes of less slender proportions.

Occasionally traces of a claw just touching the ground, as mentioned by Prof. Owen, are met with immediately behind the print proper. One is shown on a specimen in Mr. Jeffs' collection, and figured in his paper read to the Geological Association before referred to, and I have slight traces of it on one or two in my own collection. There is something very like a spur in this position in a skeleton of the pes in the Shrewsbury Museum, and a claw is shown in this position in Prof. Huxley's figures.

GROUP E.

The type of my next group, E, is a much smaller print, the pes being only $\frac{3}{4}$ in. in length. In this case

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* Vol. vii., part 3, 1842, p. 355, plates 5 & 8.

we have both the pes and the manus, the latter, however, being generally very indistinctly marked.

Pes. Not more than four digits—usually only three visible. The outer boundary of the impression usually clearly defined the whole length of the foot, and no trace whatever of a fifth digit (which, however, may possibly have existed without reaching the ground). The fourth the longest, and generally, if not always curved, with the convexity outwards, the curve being very regular from the posterior portion of the foot to the extremity of the toe. The third is slightly shorter than the fourth, and the second than the third, each very slightly curved. The first is very much shorter, and does not always make a distinct impression.

The first example I found at Storeton, and it shows a very perfect pes and less perfect manus, somewhat less than half the size of the pes.

I was fortunate enough, however, to obtain a slab from Weston bearing a continuous series of four foot-prints of the right pes and manus, and three of the left. The pes and manus were in each case abreast of each other with a space of $\frac{1}{4}$ to $\frac{3}{8}$ in. between them, the pes being outside, the breadth of the track, measuring from a line through centre of each pes, 2 in. Length of stride, $3\frac{5}{8}$ to 4 in. Extreme length of pes, $\frac{3}{4}$ in.; breadth, $\frac{1}{2}$ in. Extreme length of manus, $\frac{3}{8}$ in.; breadth, $\frac{1}{4}$ in.

I have found several examples at Weston, and a few at Storeton. Mr. Jeffs figures one from Storeton, and Dr. Black describes and figures them on a slab from Weston in the paper before referred to.

The series of quarries overlooking Weston Point extends from the new quarry on the north side of Beetle Rock, near Higher Runcorn, along the western face of the escarpment overlooking the Mersey for

about a mile to the village of Weston. The operations carried on since the date of Dr. Black's paper make it somewhat difficult to locate the position where the slab was found. He says:—"The summit of the "quarry of New Red Sandstone whence this specimen "was extracted by Mr. Feraday Smith is about 100 feet "above the level of the Mersey at Weston. The rock is "here worked perpendicularly to about 50 feet from the "top, and the seams which contain the impressions are "two in number, and are nearly three feet apart, the "higher being 24 feet from the top. Both seams consist "of from half to three-quarters of an inch of reddish silty "clay, upon which when soft the impressions have been "made, and the lower series has larger and better defined "marks than the other. The beds dip to the south-west "at an angle of about 10°, and are of a red colour and "coarse grain." A fine slab (Plate III.), about 2 ft. 6 in. by 1 ft. 6 in., and bearing nearly a hundred footprints of various kinds, was found *in sitû* in an old disused quarry about the middle of the series of quarries, and was presented by the finders, a party of students, to University College. This is, very possibly, the same bed as that from which Dr. Black's specimen was obtained, and which, allowing for the dip, might nearer the village occupy the position described. It was in an old spoil heap in this quarry that I found the specimen described above (p. 403), and several others. It is worth noting that the footprint slabs from this quarry are all much cut up by desiccation cracks.

GROUP F.

It will be remembered that the earliest described footprints were those in Dumfriesshire, attributed to Chelonians. My next group, "F," consists of forms that are very possibly of Chelonian origin. The type

may be generally described as a depressed oval pad or cushion, with four points or claws, just separated from it, along the front margin.* Examples may be seen on one of the Bootle Museum slabs and on the University College slab (Plate III). I have a tolerably perfect one from the footprint bed in the old south quarry at Storeton. It shows a well-marked oval cushion, and four toes ending in claws apparently recurved and pointing upwards, so that the roots of the claws, and not the points, have made the impressions in less perfect examples. The oval pad is usually about 1 in. in long diameter.

I hardly think that the recurving of the claws can possibly be a result of either the planting or withdrawing of the foot.

Mr. R. Harkness † mentions that the impressions of a small tortoise, having curved claws of considerable size, are met with at Weston Point, but he does not mention the claws being recurved.

The Liverpool Free Museum has, I am happy to say, just secured a large slab from Storeton, showing a fine series of these prints, which shows length of stride, 9 in., breadth of track, 8 in. Width of foot slightly larger than that given above. The original impressions having been made in a bed of fine grey clay, the sandstone casts are very perfect, and the claws may be clearly seen.

Looking at the character of the foot and the width of the track, there can be little doubt that the impressions were made by a Chelonian. The extreme rarity of Chelonian remains of this period, compared even with those of the few animals who left us their bones, is rather

* I have obtained an exactly similar mark by allowing a terrapin (*Malaco clemmys terrapen*) to walk over soft clay.

† Ann. & Mag. Nat. Hist., 2nd Series, vol. vi., p. 440.

extraordinary when we find the footprints that may be referred to this family so abundant.

Dr. Black figures a very curious footprint from his slab, which has puzzled me very much. He gives length of footprint 2 in., breadth 1½ in., length of stride 9 in. It is also described as having "short toes or claws on each side."

I have often found the impression of apparently two exactly similar feet placed, heel to heel, as it were, with the toes pointing outwards, and with these I should certainly associate Dr. Black's figure; but he mentions the tracks in two parallel lines, with the print in one track coming opposite the middle point between two prints in the opposite line. The slab is in the Geological Society's Museum in London, and on a recent visit the curator very kindly identified it for me; but fifty years of dusting, removal, &c., had rendered the prints too indistinct to give any detail whatever. There were lines of tracks across the surface, but that was all that could be made out.

The double footprint to which I have referred measures—width 1⅜ in., length ¾ in. Four toes with claws on each side (Plate II., F. 3.)

Group G.

Another form of footprint, distinguished by a sharply cut semicircular heel with three or four slender claws or toes in front, has been found in several places outside our district. Prof. Huxley describes and figures some found at Cummingstane, Elgin.*

* Staganolepis and the Footprints at Cummingstane, Elgin. Q.J.G.S., vol. xv. This paper should be read by all workers at footprints, as the author gives many hints for the avoidance of errors of observation, and remarks on the danger of concluding that the impressions were formed by an animal whose bones happen to be the first found in the same bed. In this case Staganopis remains were so found; but he only admitted that the probabilities were slightly in favour of the impressions being those of Staganopis. The wisdom

So far, the only similar form I have found in this district is from Weston quarries, where I have seen a few very imperfect ones, and I figure the best of them in outline (G, Plate II). They are shorter and broader in proportion than those described above, the breadth being 2 in. and the length from the heel to the tip of the largest toe 1⅝ in., and the curved outline of the heel forms a much smaller segment of a circle, very sharply cut. The anterior border is not sharply defined, and from it project two or perhaps three short stout toes. There is a depression behind the foot, in consequence of its pressure having forced up the mud in its rear. This feature is frequently mentioned in descriptions of this type of footprint.

Group H.

I have grouped together (H) some forms showing the impression of only three toes, though I am not at all satisfied as to their representing a tridactylate foot. In 1853 Mr. R. Harkness described† some three-toed footprints from Weston Point, which he considered probably those of birds. Unfortunately they are not figured, and the description does not give sufficient detail to identify them with any now obtainable. They were ¾ in. in length.

Mr. Cunningham, on the occasion of an excursion of the Literary and Philosophical Society to Storeton, in March, 1846, discovered what he considered to be birds' footprints.

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of his caution was shown by the discovery of remains of the Hyperodapedon in the same bed before the printing of his paper, as mentioned in a note by Huxley himself.

† Ann. & Mag. Nat. Hist., 2nd Series, vol. vi., p. 440. "Notice of a "Tridactylate Foot Mark from the Bunter Sandstone of Weston "Point, Cheshire, by R. Harkness." N.B.—At that time the Weston Sandstone was considered to be Bunter.

Canon Hume wrote an account of the excursion, which was published in the first volume of their Proceedings. He describes them as "three very distinct marks of three toes each, length about three inches." I gather from the account that some doubt was entertained by some members of the party as to their being the impressions of birds' feet, but Mr. Cunningham was very sure of it, and having, as I understand it, found some further examples, a letter from him to Dean Buckland, announcing the discovery, was read by him to the Geological Society of London. There are some examples of three-toed footprints from an old quarry in Rathbone Street figured in "The Geology of the Country around Liverpool,"* and there is a fine series of tracks on a ripple-marked slab in the Liverpool Museum.

Bearing in mind that feet having undoubtedly four toes often leave the impression of three only, I should hesitate to say positively that any that I have seen from this district were really tridactylate.

Lastly, as regards webbed footprints. In the older figures and descriptions these are often shown, but I have not seen any undoubted example from this district, though I have seen some that may owe certain peculiar appearances to the fact of their having been webbed.

Mr. Cunningham describes and figures one from Storeton in Proc. Lit. & Phil. Soc., vol. i., but I doubt the appearance being caused by webbing. Dr. Black also figures one from Weston in the paper before mentioned.

In conclusion, I do not pretend that all footprints found here would readily find a place in one or other of the groups I have sketched out; but I think they may perhaps cover most of those most commonly found, and

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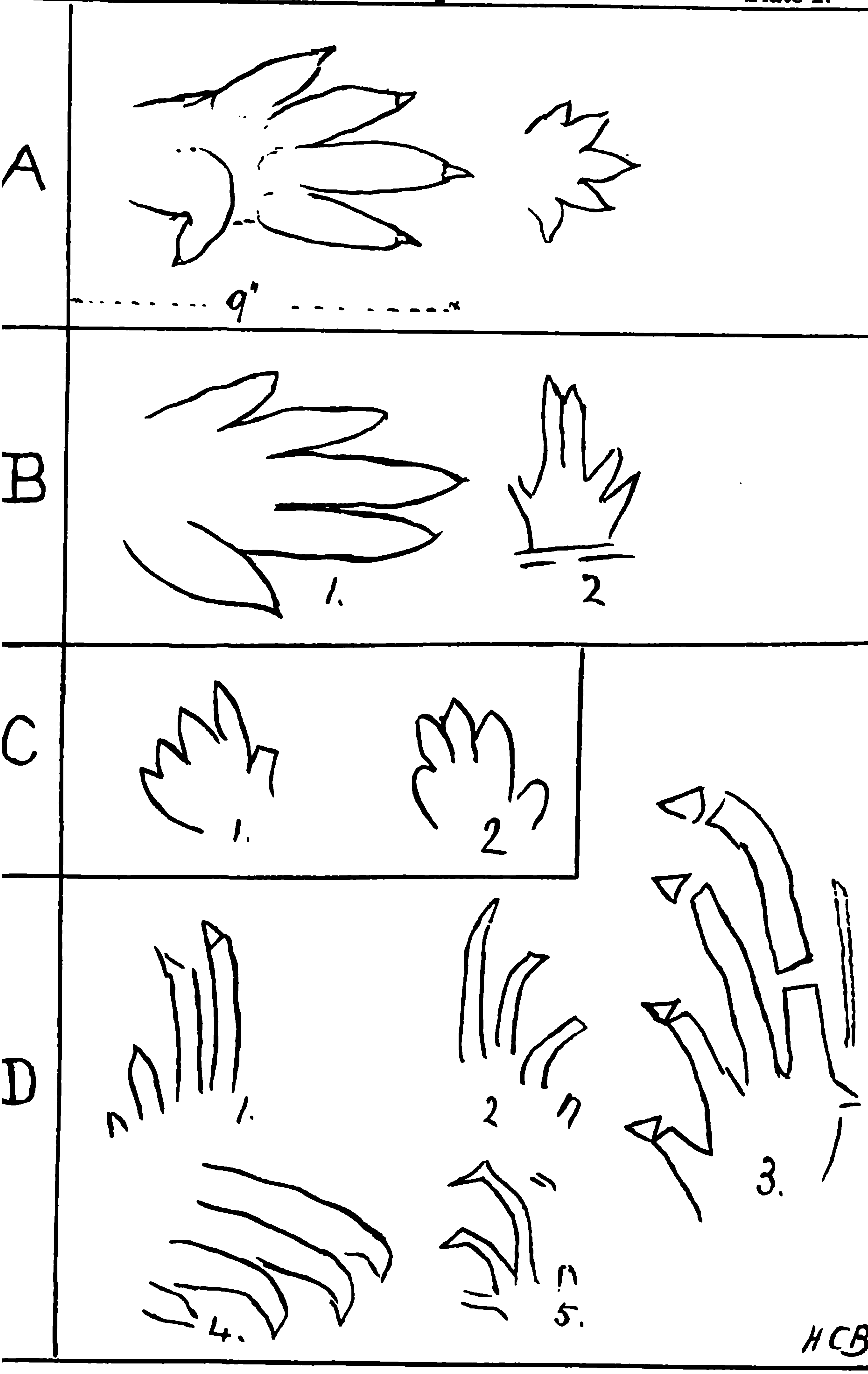
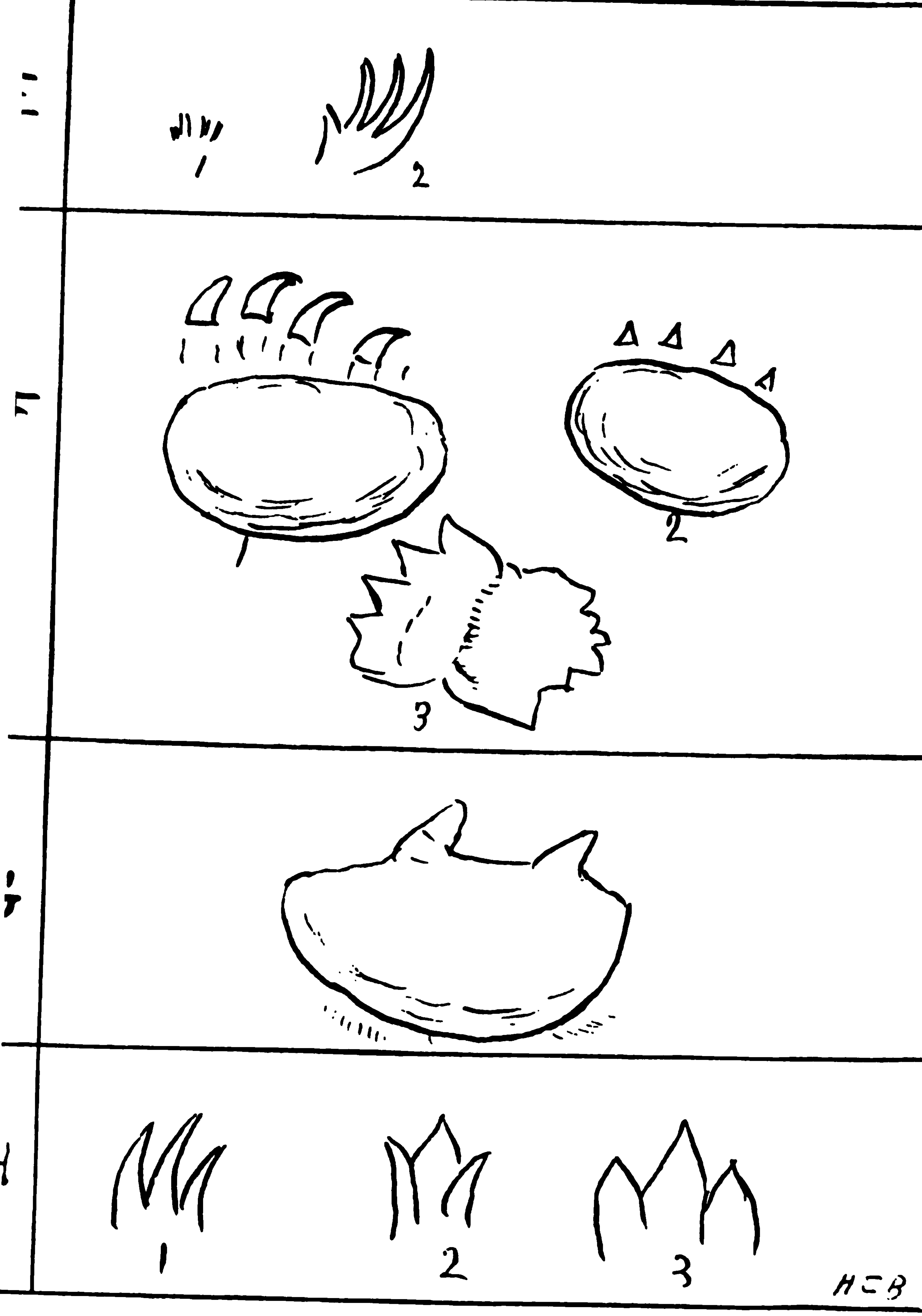
* Geology of the Country around Liverpool. G. H. Morton, F.G.S. (2nd Edition), Plate XII.



Footprints from Trias. All natural size except A
To illustrate H. C. Beasley's Paper.



Footprints from Trias. All natural size.
To illustrate H. C. Beasley's Paper.

Underside of Slab of Keuper Sandstone, from Weston.

I hope that the paper may be of some use to other workers in facilitating a comparison with the footprints from other districts and with those of recent animals. In this latter direction there is a fine field for experiment and observation, for Professor Huxley's remark in 1858, "It must be confessed that there is a great want of "recent materials in attempting to study comparative "ichnology," still holds good.

EXPLANATION OF PLATES.

PLATE I.

Outlines of Natural Casts of Footprints from the Lower Keuper Sandstone.

A Pes and Manus of Cheirotherium, about ½ natural size.
B 1 From Flaybrick Hill Slab in Bootle Museum ; natural size.
,, 2 ,, Weston Quarries ; natural size.
C 1 ,, ,, ,, ,,
,, 2 ,, Helsby Quarry, ,,
D 1 ,, Weston Quarries ,,
,, 2 ,, ,, ,, ,,
,, 3 ,, a Sewer Cutting on Oxton Heath ; natural size.
,, 4 ,, South Quarry, Storeton ; natural size.
,, 5 ,, ,, ,, ,, ,,

PLATE II.

E 1 and 2 Manus and Pes from South Quarry, Storeton ; natural size.
F 1 From South Quarry, Storeton ; natural size.
2 Drawn from several examples from Storeton and Weston Quarries ; natural size.
3 From Weston Quarries. A double footprint, probably of right and left foot. The same may be seen also on a slab from Storeton in Bootle Museum ; natural size.
G 1 From Weston Quarries ; natural size.
H 1 ,, Rathbone Street, Liverpool, figured by Mr. G. H. Morton in "Geology of Country around Liverpool ;" natural size.
2 ,, Weston Quarries ; natural size.
3 ,, Storeton South Quarry ; natural size.

PLATE III.

Slab of Keuper Sandstone from Weston Quarries, in Museum of University College, Liverpool, showing desiccation cracks and footprints of various kinds.

NOTES ON THE DRIFT OF THE MID-WALES COAST.

By T. Mellard Reade, C.E., F.G.S.

(Read 14th January, 1896).

In continuation of my paper on "The Drift Beds of the Moel Tryfaen Area of the North Wales Coast,"* I purpose putting together notes which were made at various times, as the opportunity occurred, of coastal sections in areas south of Tryfaen extending as far as Llanrhysted, nine miles south of Aberystwith.

Merionethshire Drift.

The first coastal drift south of Tryfaen of which I have any notes is where the Cambrian Railway skirts the coast immediately south of Harlech. The section is of considerable length, and I should judge about 100 feet deep. It appears to have been a sea-washed drift cliff before the construction of the railway. It is a hard rusty brown till, which weathers to a gritty loam on the surface slope. It is full of grit boulders and small gravel, its character evidently being determined by the nature of the country rock. There is not much of information to be derived from it in the absence of fresh sections.

On the shore north of Llanaber a submarine peat and forest-bed is to be seen on the shore, with stools of birch trees in situ. The whole rests upon stratified gray underclay containing scrobicularia in the vertical position in which they had lived, with both valves united. The upper part of the peat, which is just within the range of high water of spring tides, is surmounted by a pebble ridge. I observed several oak stools embedded in the pebble ridge, the largest being about eighteen

* Proc. of Liverpool Geol. Soc., Session 1892-3.

inches in diameter, of hard black oak. They have been washed out of the forest-bed.

It is curious that the pebble ridge ends abruptly to the north, sand dunes taking its place. Not a pebble is to be seen on the shore here. The whole phenomena are the equivalents—we may even say a repetition—of the Alt Mouth Post Glacial Beds.

Towards Barmouth boulder clay makes its appearance, but I had no time to specially examine it.

Cader Idris Area.

Drift Sections from Barmouth to Towyn.

Glacial Markings at Barmouth.

In September, 1890, while examining the church then being built on the side of the hill behind Barmouth, I noticed that a little to the south of the church the drift had been bared from the cliff, exposing a wonderful set of groovings and polishings of the rock. Fig. 2, Plate 1, is a section transverse to the groovings, which, from the remarkable undercutting, might not inappropriately be termed mouldings. These mouldings have a very curious twist or longitudinal cross-wind like a portion of a screw. The rock is a hard slaty Cambrian Rock, having an imperfect cleavage, the walls of the church being built of it and quarried on the site. The striæ, which were found on all the surface and in the undercuttings, were generally parallel to the groovings, but were also cross-hatched.

To the north of the church and higher up the hill is a still more curious set of groovings, having a section like Gothic mouldings (see Fig. 3, Plate 1). About 4½ yards in length were exposed (this was an old and apparently natural exposure). The mouldings were not horizontal, but dipped quickly towards the south 25° east.

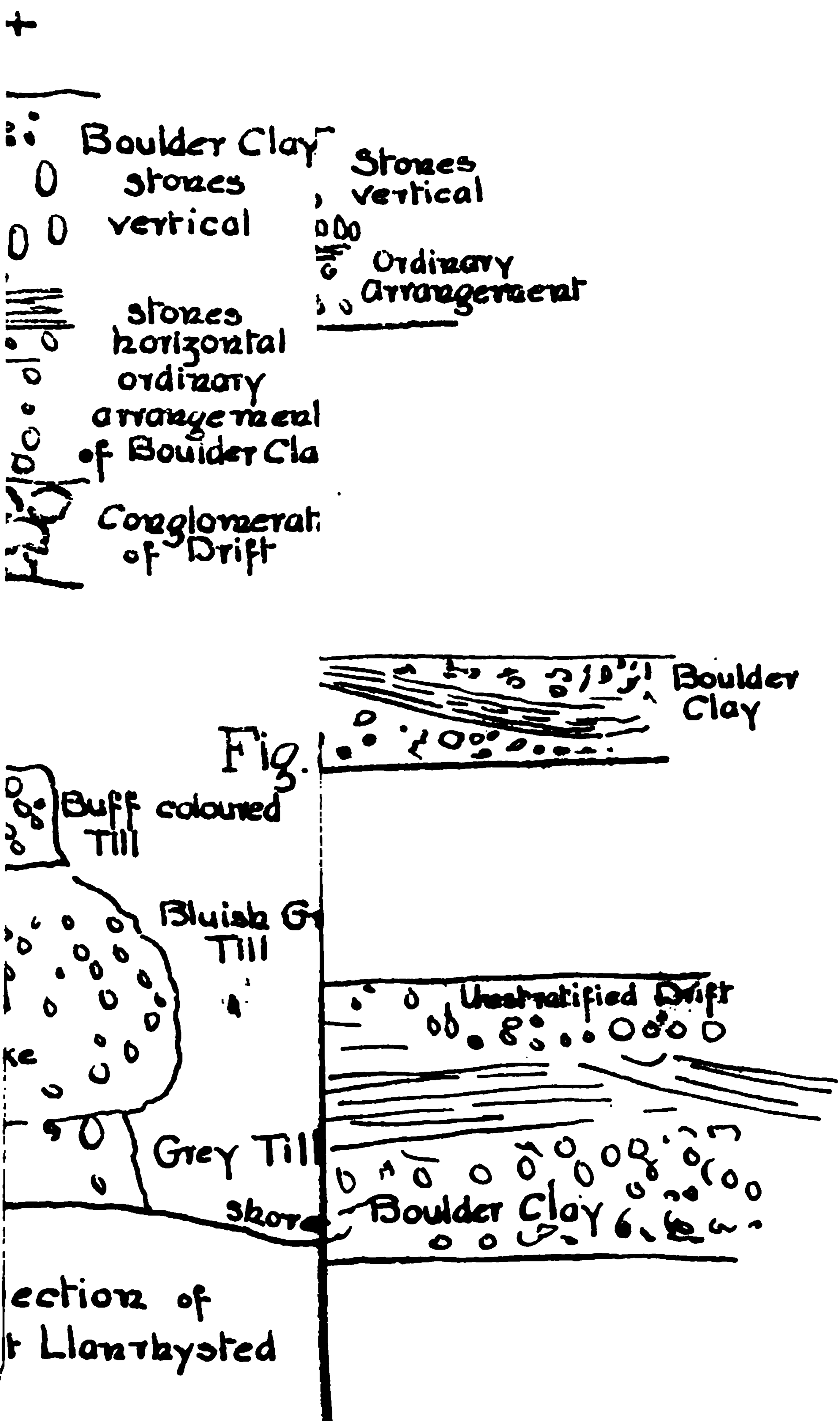
The striæ were parallel with the flutings, and therefore run north 25° west and south 25° east. The most peculiar feature was the presence of well-marked groovings on the underside of the overhanging mould, as shown in the section. The rock was slaty, cleaved at right angles to the mould, above which was an overlying hard bed of grit. There are evidences of glaciation all over the sides of the hill, projecting rocks being smoothed and rounded.*

LLWYN-GWRIL TO TOWYN.

Commencing at Llwyn-gwril, a pebble ridge extends to the rocky headland lying to the south, called Pen-glas. South of this is a long rampart of vertical cliffs of till covered with verdure, ivy growing up to the top. It is quite a remarkable green rampart. The till at the base is as hard as stone, and so tough and strong that it is difficult to drive a chisel into it. The fine clay matrix ground from the slate rocks makes it into a tough concrete. This length is protected at the foot by a pebble bank; hence the growth and verdure. Many of the stones in the till are striated, but I could not discover that they lay in any definite direction, nor did I observe any "planes of shearing." The stones lie pell-mell. I observed striæ on one of the big blocks on the beach. A boulder of volcanic ash lying on the beach measured 18 ft. by 12 ft. by 10 ft. extreme dimensions, but I could see on it no signs of glaciation. Fig. 1, Plate 1, gives a section of a portion of the cliff where sufficiently exposed for observation.

* Mr. H. P. Cushing, describing the striations on the islands in Glacier Bay, Alaska, from which the Muir Glacier has but lately retreated, says: "Striæ ascend and descend, both straight and obliquely; curve in various ways and in various planes; occur *on the lower side of overhanging surfaces;* not uncommonly produce bevelled edges. The ice evidently fitted itself to them like a glove."—Notes on the Muir Glacier Region, Alaska.—American Geologist, October, 1891, p. 228.

PLATE I


Boulder Clay
stones
vertical
stones
horizontal
ordinary
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of Boulder Cla
Conglomerat
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Fig.
Buff coloured
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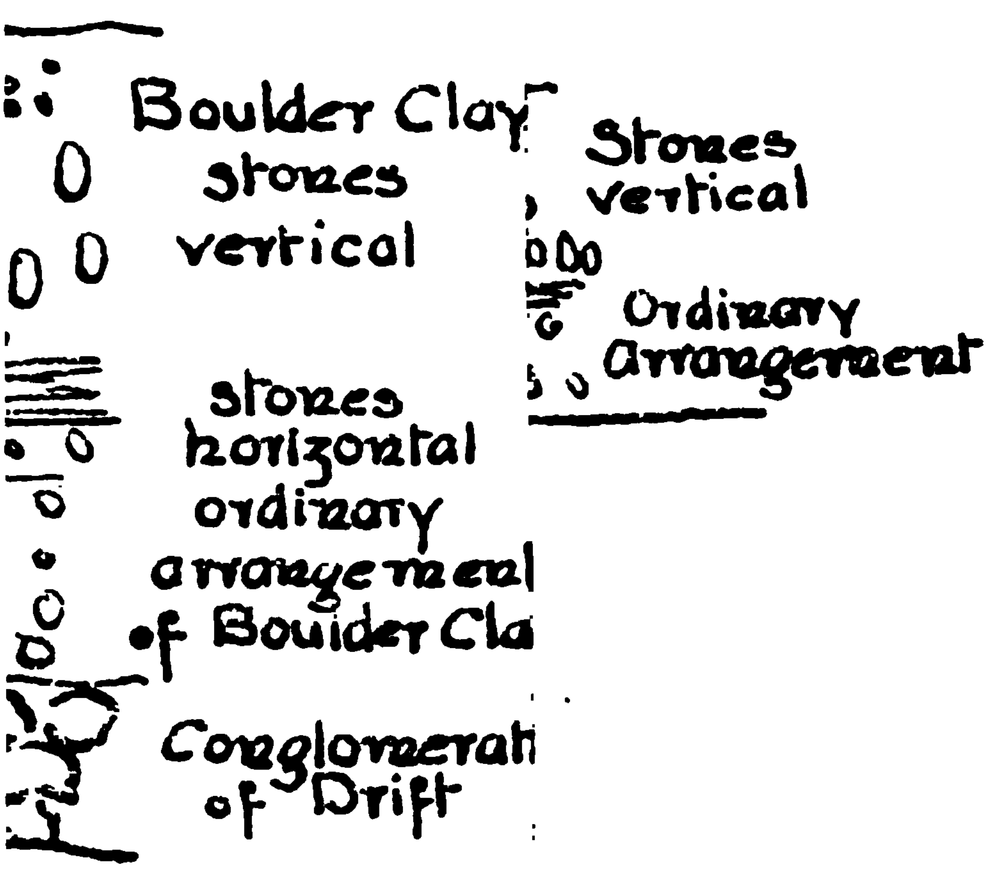
The striæ were parallel with the flutings, and therefore run north 25° west and south 25° east. The most peculiar feature was the presence of well-marked groovings on the underside of the overhanging mould, as shown in the section. The rock was slaty, cleaved at right angles to the mould, above which was an overlying hard bed of grit. There are evidences of glaciation all over the sides of the hill, projecting rocks being smoothed and rounded.*

Llwyn-gwril to Towyn.

Commencing at Llwyn-gwril, a pebble ridge extends to the rocky headland lying to the south, called Pen-glas. South of this is a long rampart of vertical cliffs of till covered with verdure, ivy growing up to the top. It is quite a remarkable green rampart. The till at the base is as hard as stone, and so tough and strong that it is difficult to drive a chisel into it. The fine clay matrix ground from the slate rocks makes it into a tough concrete. This length is protected at the foot by a pebble bank; hence the growth and verdure. Many of the stones in the till are striated, but I could not discover that they lay in any definite direction, nor did I observe any "planes of shearing." The stones lie pell-mell. I observed striæ on one of the big blocks on the beach. A boulder of volcanic ash lying on the beach measured 18 ft. by 12 ft. by 10 ft. extreme dimensions, but I could see on it no signs of glaciation. Fig. 1, Plate 1, gives a section of a portion of the cliff where sufficiently exposed for observation.

* Mr. H. P. Cushing, describing the striations on the islands in Glacier Bay, Alaska, from which the Muir Glacier has but lately retreated, says: "Striæ ascend and descend, both straight and obliquely; curve in various ways and in various planes; occur *on the lower side of overhanging surfaces;* not uncommonly produce bevelled edges. The ice evidently fitted itself to them like a glove."—Notes on the Muir Glacier Region, Alaska.—American Geologist, October, 1891, p. 228.

PLATE I


Boulder Clay
stones
vertical
stones
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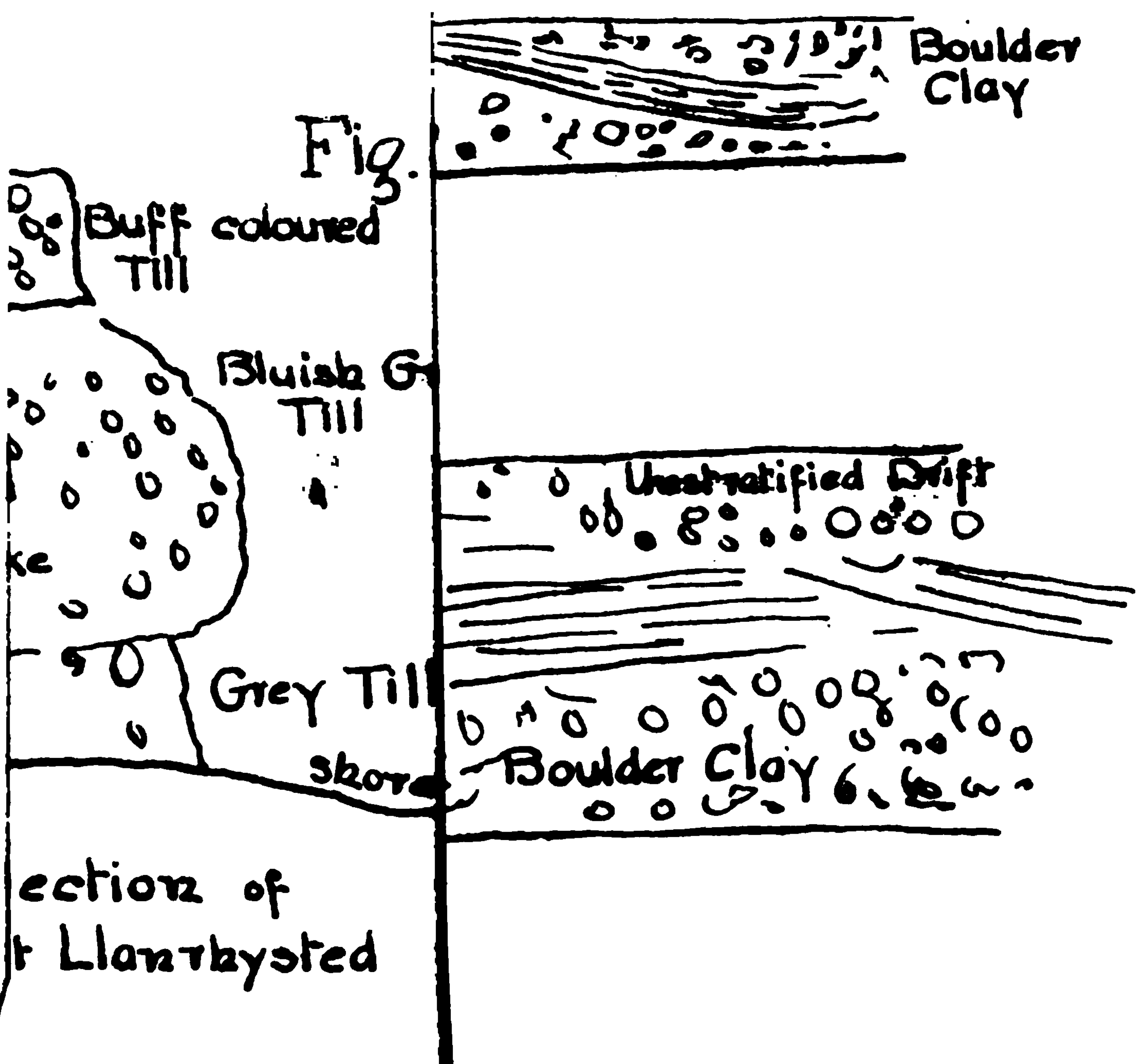
Boulder
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Fig.
Buff coloured
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Bluish G
Till
Unstratified Drift
Grey Till
shore
Boulder Clay
ection of
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Further south the drift becomes a sort of boulder rubbish and clay—a glacial rubbish tip—and then rudely-stratified beds begin to set in, and the cliffs are not so high. There are some immense blocks of stone on the beach, up to 40 tons, I should judge. Some of the big, angular blocks are of the wavy banded, slaty rocks found in the headlands, and in the quarry above by the side of the railway.

I noticed a big block of slaty agglomerate having pieces of blue or purple slate fragments in it. There are many well-rounded boulders of a gray porphyritic rock, which, from its frequency, I judged must be a Welsh rock. Mr. Harker, to whom it was submitted, says—"The diabasic rock (sliced) I cannot identify with any particular one in North Wales or the Lake District. It is of a coarser texture than the usual Carnarvonshire varieties (almost approaching Gabbro), and the augite is more deeply coloured than that of the Welsh diabases."

Most of the boulders and gravels in the drift appear to be of the Cader Idris volcanic type. The blocks on the shore are worn quite smooth with the continual battering of shingle against them.

The Cambrian Railway from Barmouth to Towyn runs on the platform of drift, which lies with a gentle slope against the bordering hills, and out of which the sections described have been cut by the sea.

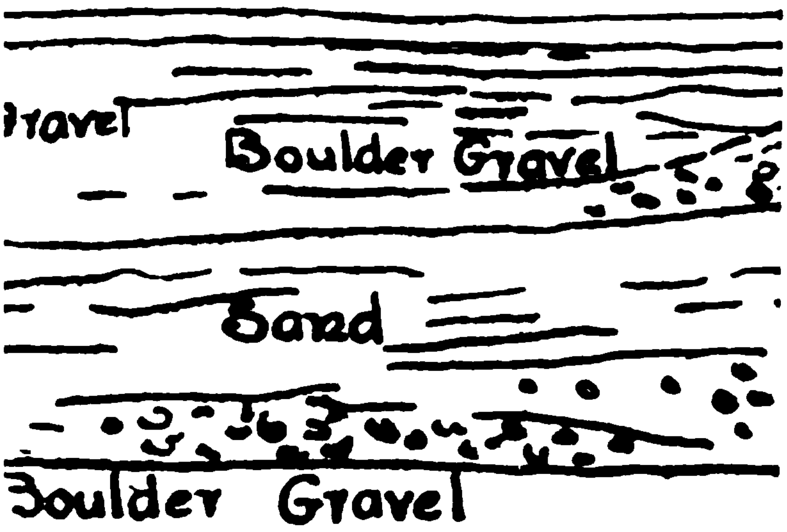
Fig. 9, Plate 2, is a section of the stratified sands and gravels, with patches of boulder clay. North of Aber Dysynni and still further south, and nearer to the mouth of the Dysynni, by Ton-fanau Farm, is boulder clay associated with finely-laminated clay without stones, as shown in section, Fig. 10, Plate 2.

Here also is to be observed a curious arrangement of stones in the boulder clay also seen near Towyn. In the bed above the sand seam, Fig. 11, Plate 2, the stones are nearly vertically on edge, like what is known among engineers as "hand-pitching," while at the base the stones lie in the clay in all directions.

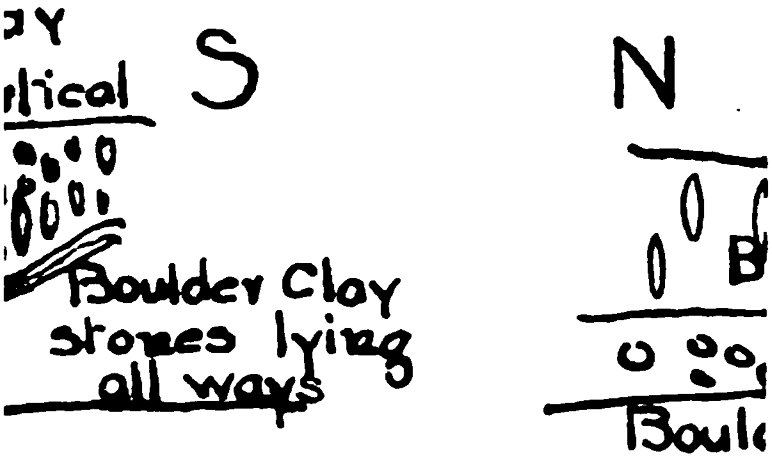
To the south of the Dysynni river there is an alluvial flat upon which the sea has thrown up a rampart of pebbbles and boulders in the form of a pebble ridge more than a mile long. A large proportion of these stones are Aberystwith grits, though such are not noticeable in the drift.

Near to but to the north of Towyn the boulder clay and sands come in again, and the vertical arrangement of the stones in the upper bed of boulder clay recurs, as shown in Fig. 4, Plate 1, while the ordinary arrangement, or want of arrangement, occurs in the bottom bed. Figs. 6, 7, and 8, Plate 1, show some of the relations of the laminated sands and gravels to the boulder clay. The boulder clay at Towyn is of a dark brown colour, differing considerably from the gray till nearer Barmouth already described.

On the shore there was an expanse of denuded boulder clay, in which the stones are set on edge in parallel lines having a north and south direction; of course this is but a horizontal section of what appears in the cliff in vertical section, but whether the latter have the north and south alignment it is impossible to say. There is a large boulder of volcanic ash embedded in the boulder clay having its longer axis N.E. and S.W., and another occurs striated on the top, the striæ being N. 20° E. A boulder also occurs near the railway bridge at Towyn embedded in till, showing striæ on the underside and side, having a direction north-east, which is also that of


ravel
Boulder Gravel
Sand
Boulder Gravel


ed clay
No Stones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the longer axis. It is of volcanic ash, and measures 5 ft. by 3 ft. by 2 ft. 6 in.

A great deal of the subsoil under the alluvial plain of Towyn is of boulder rubbish, which I understand caused the contractor for the sewerage works much trouble. From Towyn to Aberdovey no cliff sections of drift occur.

INLAND DRIFT.

Generally speaking there seems to exist the same absence of large deposits of drift in the inland valleys as in other mountain areas.

In the valley of the Mawddach, below Dolgelly, a gravelly drift occurs, which I examined in the excavations for the new wing of Dr. Williams' Endowed School for Girls, of which I was the architect; the gravel is considerably waterworn, is mixed with current bedded sand, and contains many large rounded boulders.

It appears to me to belong to the River drift period succeeding the Glacial, and to be an equivalent deposit to that found in the River Terraces of the Dee Valley.

Near Arenig Station the railway cuts through and exposes a good section of the drift typical of the neighbourhood. It lies under a rocky cliff on a spur of Arenig, and is composed of gravel cemented together with a hard light brown loam. It is full of immense blocks of a greenish coloured ash, one of which measured 15 ft. by 10 ft. by 6 ft. outside dimensions. They appeared to have fallen from the cliff immediately above.

In the stream from Mynydd Bychan, near the intake of the Towyn Water Works, there is a section cut by the stream through drift of a morainic character of the usual hill type, consisting of angular and subangular slates and fragments of slate rocks.

An exception to this apparent absence of great drift deposits among the mountains is a remarkable mound

blocking up the valley immediately below Tal-y-llyn. According to my aneroid observations, the top of this mound is but 352 ft. above the sea level, the level of the lake being, according to the same observations, 277 ft. above the sea, while the river flowing out of the lake at a point where it cuts through the mound was 252 ft. above the sea.

The river cliff on the right bank is here 40 ft. high, and consists of boulder clay, and I infer from the topographical appearance of the mound, as also from the soil, that the mound is all composed of boulder clay. This mound only apparently blocks the valley, the river having cut through its dam on the left bank between the side of the valley and the mound. The mound extends a considerable distance down the valley below the lake, and its surface looks like a billowy sea. The gradient of the river bed is steep, which may account for the river keeping to its course, and not cutting out more of the boulder clay laterally by oscillating and winding from side to side. The preservation of this mound is somewhat unique.

Observations on the lake shore to the north-west showed low boulder cliffs, and further on stiff boulder clay and slate fragments to the north-west of the marginal road, while at the head of the lake a road section showed buff coloured clay with few stones. The lake is very shallow on the north-western margin.

Ascending the road from Dol-ffanog to Corys there are glacial markings on the slate rock about north 30° east; this is covered by a very fine slate débris, the cleavage is about north-east. Near the summit level of the road to Corys the slate rock is glaciated, presenting a smooth knobby appearance, but no striæ. All the slate rocks at

Corys are rounded by glaciation, but they are too much weathered to show striæ.

General Remarks on the Cader Idris Area.

It is evident from the glacial groovings and mouldings on the side of the hill at Barmouth that at one time a very important glacier filled the valley of the Mawddach, and extended forward into Cardigan Bay, but its relations to the drift deposits already described I do not propose to discuss.

The same topographical distribution of the drift occurs in this area as in the Tryfaen area, that is to say we find typical till or hill drift lying banked up against the hill slopes, while the stratified deposits of sand and boulder clay come in as the estuary of Dysynni is approached. Upon this extended plain the stratified drifts and boulder clays have been laid down, have again been largely denuded, and then covered with a broad expanse of alluvium. Across the alluvial valley or marsh land the sea has built a rampart of pebbles and boulders, displaying from the shore side an absence of vegetation that is both monotonous and dismal.

The curious phenomenon of the pebbles of the upper bed of boulder clay being set vertically on edge may be of more general occurrence than I suppose, but it is one that I have not observed to be so marked elsewhere, and no very satisfactory explanation presented itself to me on the ground, though I paid considerable attention to the point.

Mid-Wales.

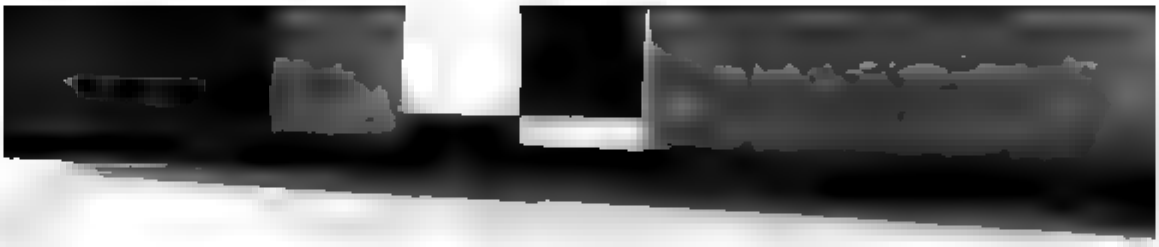
Drift Sections from Borth through Aberystwith to Llanrhysted.

From Borth to Aberystwith the coast is mostly rocky and precipitous, but at Wallog Bay there was in 1885 on

the south side an exposure of till interstratified with a gravelly loam, this section being the most stratified of any I saw in this neighbourhood. At the north side of Clarach Bay I noted till with angular and sub-angular boulders capped with gravel and waterworn stones, above which was sand and finally waterworn and sub-angular boulders. In the excavations for the foundations of the new infirmary, Aberystwith, I observed a stiff gray till about twelve feet deep, including the top-wash of the till, about 2 ft. 6 in. thick. The till occupies a sort of plateau, and there are some rounded stones in it.

South of Aberystwith the coast from Allt-wen southward is for a considerable distance most desolate-looking, being composed of big blocks of Aberystwith grits and slates, piled up pell-mell, with no vegetation to relieve their monotonous gray colour; the cliffs then become more vertical, without talus-rubbish, and near the lime-kiln are capped with stiff gray till. A very remarkable section of till then occurs, of which a section is given in Fig. 12, Plate 3. The till at A seems to be banked up against a pre-glacial cliff. Fig. 13, Plate 3, shows that the till has a sloping stratification from the face of the cliff, as if tipped over the cliff. Fig. 14, Plate 3, shows the till at B in transverse section on a larger scale. The remarkable profile is due to its hardness and tenacity, the under-cutting being the effect of battering by the shore shingle.

At E pluvial denudation has cut out the till into very noticeable earth-pillars, of which Fig. 15, Plate 3, is a rough sketch. Fig. 16, Plate 3, shows the junction of the till with the rock. It is here covered with a stratified bed. I observed some lightly striated stones and others not of the immediate neighbourhood, but no granites or greenstones.



g. 15

d Undercut Cliffs
t E

At Llanrhysted there are good sections of the gray till, here also very hard and tenacious, and standing out with the profile shown in Fig. 5, Plate 1, in extensive cliffs. The country about does not yield many varieties of rocks, and the till partakes of the same character. The pebbles on the beach are of much more varied rocks than the stones of the till.

These observations here recorded do not pretend to the detailed and systematic character of some of my drift papers. As already said, they were made at various times as opportunity occurred, and before I had commenced a microscopic examination of drift materials, which, if made, would probably in most cases have thrown more light upon their nature and origin.

It will be noticed that the Scotch and Lake districts erratics, which occur so plentifully from Macclesfield to Moel Tryfaen, have no place in the drift herein described. I am far from saying that they are entirely absent—to prove a negative is impossible; but this I can say, that I have looked carefully for Eskdale granite and other typical rocks without finding one example. It is not my object here to enter into theoretical questions further than to say that the observations recorded are in nowise opposed to the theoretical views I have elsewhere expressed.

THE BERWICKSHIRE COAST: A STUDY IN PHYSICAL GEOLOGY.

By T. Mellard Reade, C.E., F.G.S., F.R.I.B.A.

(Read 11th February, 1896.)

The coast of Berwickshire, though presenting magnificent sections of Silurian, Old Red, and Carboniferous rocks, seems to be seldom visited by English geologists.

The interesting nature of the geology of the county is fully shown in the able memoir by Mr. now Sir A. Geikie, published by the Geological Survey in 1864, and for many years after its perusal I had been longing to visit the district. The opportunity came in the summer of 1895, when I found that the geology was as interesting as I expected, while the beauty of the coast scenery far exceeded any conceptions I may have formed of it. This I may add was largely due to the wonderfully brilliant and varied colouring of the rocks, which, passing from bright red through purple to the darkest of shades, are here and there variegated with yellow and grey. These richly coloured cliffs, ever changing their hues and details as the sun lights up a headland or a pinnacle, or a cloud throws the precipitous rocks into the deepest shade, are set in the greenest of green verdure, and are a real joy to the artist's eye.

Interpreted in the light of geological knowledge, they lose none of their artistic interest while yielding intellectual pleasure of another kind. Indeed, I maintain that a general knowledge of the structure and relations of rocks is of the same importance to the artist who would feelingly portray them as is anatomy to him who would correctly draw the human figure. But, furthermore, the coast of Berwickshire presents problems of physical and dynamical geology of surpassing interest.

DESCRIPTIVE.

The Coast.—The whole of the coast scenery and geology that I purpose to deal with in this paper is comprised in Sheet 34 of the Ordnance Survey of Scotland. It was published, geologically coloured, in 1863 from the surveys of Messrs. Howell and Geikie, with a descriptive memoir by Geikie, written in that interesting and powerful style of which he is a master. Of this information I make free use, and must begin by expressing my indebtedness to the excellent work, considering the date of publication, embodied in the map and memoir.

The length of the coast line estimated roughly, without measuring the embayments and sinuosities, is fully twenty miles, and the actual sea cliffs vary from about 100 to 300 feet high, but the sloping hills behind attain a maximum altitude of 528 feet three-quarters of a mile west of St. Abb's Head, and a quarter of a mile from the coast.

About six miles of this coast line from Berwick northwestward is composed of Carboniferous rocks from the Calciferous Sandstone series (the Scottish equivalent of our Lower Limestone Shales) upwards. It is a strip not more than a mile and a quarter broad in the widest part, measuring from the coast line, being cut off from the Silurian to the westward by a great and remarkable fault extending from Berwick to Burnmouth. From Burnmouth to Eyemouth, about two and a half miles, the coast consists of highly folded and compressed beds of greywacke, through which dykes and veins of porphyrite, and, at a later date, greenstone, have been injected and ramify.

These cliffs may be examined by walking from Eyemouth to Burnmouth along the narrow margin between the fences of the cultivated land and the edge of the

cliffs, or on a very calm day by rowing round in a boat; both methods may be necessary to get an adequate idea of their form and structure.

In the western horn of Eyemouth Bay we see the Old Red Conglomerate resting on ash beds. Crossing this headland we again come on to intrusive porphyrite, which continues to Cullercove Point, when we again meet with the Silurians. These continue for a distance of about 1½ miles, measured in a straight line, to Coldingham shore. They are strikingly red in hue until nearing Coldingham shore, when they become a yellowish grey. A traverse northwestwards will take us across a strip of Old Red a little over a third of a mile wide, when we again meet with the Silurians. The cliffs forming the wild headland from Coldingham shore (now called St. Abbs) to St. Abbs Head are nearly all dark purple porphyrite that have resisted the continued assaults of the sea better than the surrounding sedimentary rocks. For another five miles westward the cliffs are all Silurian, which can be seen at Fast Castle, built on a narrow promontory, the original of the Wolf's Crag in the Bride of Lammermoor, the last refuge of the ill fated heir of Ravenswood.

A long drive from Eyemouth over Coldingham moor to Fast Castle gives one a good idea of the original wild bleak nature of the county, now partially subdued by agriculture. Another drive over the same moor to the ruins of St. Helen's Church brings us close to the celebrated Siccar Point, where occurs the wonderful illustration of unconformity already alluded to, and to be explained in detail hereafter.

Inland.—The inland scenery begins in cultivated land lying in long curving slopes, and extending from the coast to the foot of the low hills, where it gives place to

pasture and then to moorland. The highest point is the camp on Lamberton Moor, 712 feet above O.D., about 1½ miles from the nearest part of the coast, and the same distance south by west of Burnmouth. At this high level, on approaching the entrenchment, we pass a row of old weird looking thorns. High up on the moor, between the camp and the sea, is the race-course, a narrow lane of turf in loop form on very undulating ground well fitted to test the wind of the horses.

The valleys cut by denudation out of these Silurian and Old Red Sandstone rocks are more fertile than the uplands and undulating coastal plains. At Ayton, on the river Eye, or the Eye Water in local phraseology, and from thence to Eyemouth, there is a goodly extent of woodland valley. These river valleys and burns are cut down very deep into the bed rock, and during a "spate" the waters rush down in turbid torrents, showing plainly what a great quantity of earth is removed on such occasions. One day we noticed that Eyemouth Bay, which receives the drainage of the Eye Water, was turbid and of a deep chocolate colour, evidently due to the torrents of rain that fell all the previous day and night. This turbidity was superficial, for on some of the breakers outside, the green sea water surged up from below the chocolate coloured surface water. I was much struck with this evidence of denudation, as I find that the rain fall at Eyemouth the previous year (1894) was only 25 inches.

The general appearance of the country shows that the cultivated land has been largely won from the moorlands, and that the original appearance of the landscape was quite in keeping with the wild border tales we read, and the legends that have woven themselves about the more historic localities.

Silurian.—These rocks, which occupy the largest area of the map, are as already stated composed of beds of blue, grey, and red or purple greywacke highly folded over the whole area, as may be seen in the cliffs and in the outcrop of the vertical edges of the beds where they are seen in the moorland.

In the Survey Memoir and Map these rocks are considered to be Lower Silurian (Ordovician), but Dr. Lapworth, who has done much towards working out the succession in the southern uplands, considers them to be greywackes, belonging to the Gala or Llandovery Tarannon group.

They contain fossils such as *Monograptus Priodon*, &c., characteristic of that period, and answer to the Newlands and Dailly groups of the Girvan district.*

Sir Archibald Geikie, in the 1892 Edition of his Geological Map of Scotland, colours them as Llandovery.

The general strike is, according to Geikie, N.E. to S.W., or N.N.E, to S.S.W., and he states that this feature is common to the Silurian tract of the South of Scotland. It is so in Wigtonshire, as I can aver from personal knowledge. These folds are, I believe, long boat shaped anticlinals lying side by side with similar synclinals. The convolutions of the rocks can be seen in transverse section in the cliffs, and are shown in the rapid sketches I exhibit made from a boat while rowing between Burnmouth and Eyemouth, and they are typical of the remainder of the Silurian cliffs. Stacks of rocks are curved out of these complicated structures by the action of the sea, and one of these is to be seen between

* See The Girvan Succession, Q.J.G.S., 1882. The Moffat Series, *Ibid*., 1878. The Ballantrae Rocks of the South of Scotland, Geo. Mag., 1889.

Cullercove and Lymkin Burn. Looking at one face it appears to be composed of horizontally bedded rocks, but on another face we see the same beds curved and contorted. This at first looks very singular, but a closer examination shows that one joint face approaches a right angle to the other, so as to give a longitudinal section on one side and a transverse or oblique section on the other. The Wolf Rock is a plug of porphyrite left as a stack by the denudation of the surrounding greywackes. The Breeches Rock close to it is a compound of Silurian beds, with a parallel dyke of porphyrite, and owes its form and name to these and the cavity between them.

They are both a little north of Burnmouth. As I have already stated, it is difficult to examine the cliffs from the absence of shore, of which there is only a little at Burnmouth and Eyemouth, while Coldingham shore is mostly flanked by low land. It is possible to get along the foot of the cliffs between Cullercove Point and Coldingham Bay. At Siccar Point, in the north-western corner of the map, good sections are seen of the shales and greywacke-beds of the Silurian, and here is to be seen a large expanse of Upper Old Red breccia or conglomerate, full of angular fragments and boulders of the Silurian lying upon the upturned edges of the shales and greywacke. Looking down from the top of the cliff, this slightly inclined "cake of conglomerate" is plainly seen surrounded by the Silurian which has been stripped by the denuding action of the sea, and shows the edges of the beds striking north-easterly. A closer inspection shows that the conglomerate is cemented together by a deposit of carbonate of lime, full of minute fragments of Silurian rock, and that this is again cemented to the shale below. I managed to break off two hand specimens shewing the unconformity, which I exhibit. The Silurian

beds on examination are seen, where the shales have been denuded so as to expose the bedding-planes, to be covered with casts of suncracks.* In a cove close by we see the Upper Old Red conglomerate spanning and forming the roof of a cave about 20 feet across, a testimony to its strength; the walls of the cave being of nearly vertical Silurians.

Walking westwards we see occasional exposures on the cliff at high levels of beds of red sandstone lying nearly horizontal and transverse to the Silurians they cover. Still further on towards Greenheugh Point, there are cliffs of Upper Old Red Sandstone showing a regular and considerable dip to the northward. So far as appearance goes they might easily be mistaken for Triassic sandstones. The brilliant colouring of the cliffs is most striking, but at Fast Castle the rocks put on a more purple-black and sombre hue.

Hutton, in his Theory of the Earth, gives a good description of these cliffs from Dunglas Burn to Eyemouth. (Vol. i., pp. 454-467). He says, "But at Siccar Point we found a beautiful picture of this junction was laid bare by the sea. The sandstone strata are partly washed away and partly remaining upon the ends of the vertical schistus; and, in many places, points of the schistus strata are seen standing up through

*The fact that these beds of "Alpine Schistus" had been laid down horizontally did not escape the keen observation of Hutton. He says that in consequence of the beds being separated (that is the shales being denuded from between the beds) he had good opportunities of observing the original formation or stratification of the schists. "Here we found the most distinct marks of the strata of sand modified by moving water. It is no other than that which we every day observe upon the sands of our own shore when the sea has ebbed and left them in a waved figure, which cannot be mistaken. Such figures are extremely common in our sandstone strata; but this is an object which I never had distinctly observed in the Alpine Schisti." Vol. i., pp. 459-460. See also Playfair's Illustrations of the Huttonian Theory, p. 221, and Lyell's Elementary Geology, 4th Edition, pp. 59-60.

among the sandstone, the greatest part of which is worn away. Behind this again we have a natural section of those sandstone strata, containing fragments of the Schistus." The "Schisti" of Hutton are the Lower Silurian greywackes of this paper. Sections showing unconformity between the coal strata and the schistus are also noted. There is wonderful acumen, depth of thought, and power of observation in this chapter.

IGNEOUS ROCKS.

The igneous boss of rock forming St. Abbs Head, and the numerous dykes ramifying through the Silurian are in the nomenclature of the survey maps "Felstone." Since the survey was made and the memoir written, the science of microscopic petrology has arisen and developed in a remarkable manner, and much more is known of the striking changes which have taken place in the mineralogical structure of rocks of this character since they were first injected into the clastic rocks, or extruded at the surface in lava streams.

Prof. J. W. Judd, F.R.S., kindly examined some of my micro-slides cut from these rocks. He considers that No. 1 from St. Abbs Head is probably a porphyrite (altered andesite); another, No. 2 from Hare Point, near Eyemouth, undoubtedly a Mica-hornblende porphyrite, much less altered than No. 1. Two specimens from dykes on the shore at Burnmouth, Nos. 3 and 4, he classes as much altered porphyrites; one fine, the other coarser grained. Three from near the Breeches Rock, Burnmouth (Nos. 5, 6, and 7) are, the one No. 6, Mica porphyrite, the other two much altered Mica porphyrite. No. 8, from dyke south of Breeches Rock, Burnmouth, is probably a Pyroxene-porphyrite, much altered. No. 12, from Eyemoth, is a Mica quartz porphyrite, much altered. Prof. Judd adds "There is a remarkable family likeness

among all the igneous rocks. In all cases the original minerals are all reduced to the condition of pseudomorphs, so that there is often much difficulty in determining the species to which they originally belonged. There can be little doubt that originally they belonged to the class of andesite lavas. In most cases, the ferro-magnesian silicates are converted into chlorites and other decomposition products, but these in some cases can be seen to retain the form of biotite and hornblende. Although the original substance of the felspars has been so far destroyed, in a few cases the lamellar twinning can be detected under crossed Nicols. In nearly every case, however, the outlines of the pseudomorphs and the traces of zoning are strongly suggestive of plagioclase felspars. Only in one case is quartz present, and then only in comparatively small quantities."

"In the Upper Old Red Conglomerate of Siccar Point there are fragments of all the old lavas, but these are in a much more altered condition even than in the lava streams and dykes—as might have been expected under the circumstances."

Since this microscopic examination was made by Prof. Judd, Mr. Philip Holland, F.I.C., has been kind enough to analyse Nos. 1, 2, 5, 6, and 8 for me, which analyses being submitted to Prof. Judd he remarks as follows:—"I am much interested in Mr. Holland's analyses which you sent me. I think that the chemical and microscopical evidence are in perfect agreement; Nos. 1 and 8 correspond well with pyroxene-andesites, which have been altered into porphyrites. Nos. 2, 5, and 6 are more acid or mica-andesites (possibly mica-hornblende-andesites) similiarly changed to porphyrites. The amount of calcium carbonate in 5 or 6, shows that the amount of change which these two rocks have under-

gone is very great indeed." Mr. Holland's analyses are given on page 430. The porphyrite dykes occur in groups ramifying through the Silurian greywacke, and often branching out in a vein-like manner. The porphyrite boss of St. Abb's Head has no doubt been originally buried in greywacke, which has been removed from above and around it by combined subaerial and marine denudation.

As to the age of these felstones or porphyrites, Geikie says as fragments of them are found in the Upper Old Red Conglomerates they must antedate that formation. As they pentrate the ash beds of the Lower Old Red they are either coeval with them or of later date. Geikie classes together the felstones of the Silurian and the Lower Old Red "from the impossibility of rigorously separating them in chronological order."

LOWER OLD RED SANDSTONE.

The Valley of the Eye-water from Reston to Ayrton appears to be cut in the Lower Old Red Sandstone and Conglomerate.

Sections of these rocks can be seen in the westward promontory of Eyemouth Bay. "Excepting for the presence of some fragmentary plants and crustaceans, the position of these beds in the stratigraphical series would be very obscure."* These rocks are also exposed on Coldingham Shore, and at the Fort at Eyemouth are capped with a cake of Upper Old Red Sandstone. The ash beds as already described are penetrated with intrusive veins and dykes of felstone, so mixed up and incorporated in places that it is difficult to say where the one ends and the other begins.

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* See Geikie's Text Book, p. 713. The maximum depth of the Lower Old Red in the central basin of Scotland is over 20,000 feet.

Portion for Analysis dried at 100° C.	No. 1. Felstone, St. Abbs Head.	No. 2. Felstone, Hare Point, Eyemouth.	No. 5. Near Breeches Rock, Burnmouth.	No. 6. Near Breeches Rock, Burnmouth.	No. 8. Dyke 8 of Breeches Rock, Burnmouth.	
SiO_2	56·52	60·50	67·00	66·61	58·36	*Silica.*
Al_2O_3	17·43	17·98	15·59	15·54	14·81	*Alumina.*
Fe_2O_3	4·87	4·54	0·34	0·29	3·78	*Ferric oxide.*
FeO	0·36	1·03	1·22	1·18	1·27	*Ferrous oxide.*
FeS_2	—	—	—	1·50	—	*Iron pyrites.*
TiO_2	1·18	0·48	0·46	0·32	0·97	*Titanic oxide.*
MnO	0·38	0·28	0·31	0·26	0·32	*Manganese monoxide.*
$CaSO_4$	—	—	0·10	0·13	0·10	*Calcium sulphate.*
CaO	5·12	1·03	—	—	—	*Lime.*
$CaCO_3$	—	—	3·89	3·93	4·79	*Calcium carbonate.*
$MgCO_3$	—	—	2·50	2·60	3·51	*Magnesium carbonate.*
MgO	7·14	3·90	0·18	—	3·87	*Magnesia.*
K_2O	1·94	2·62	2·16	2·13	1·70	*Potassium oxide.*
Na_2O	2·67	4·70	3·87	3·66	3·98	*Sodium oxide.*
Combined water	2·28	3·33	2·08	2·20	2·60	
	99·89	100·39	99·70	100·35	100·06	
Sp. Gr. of the crushed Rock	2·852	2·592	2·731	2·787	2·827	
		Total CO_2	3·02	3·15	3·97	per cent.

The CO_2 found by experiment has been assumed to be entirely combined with lime and magnesia in Nos. 5, 6, 8, though some may possibly be united to the ferrous oxide.

(Signed) PHILIP HOLLAND, F.I.C.

UPPER OLD RED SANDSTONE.

This formation having been already partially described in connection with the unconformity at Siccar Point, it will only be necessary to say here that the Upper Old Red Sandstone is exposed in cliff sections along the shore for a distance of about 3 miles west of Hirst Rocks. The conglomerate reaches a height of 560 feet at Chester Hill, near Burnmouth, and 1,345 feet at Monynut Edge in sheet 33.

Being rather taken with the remarkable example of unconformity at Siccar Point, and the exceeding toughness of the rock constituting the base of the Upper Old Red breccia, I thought that a detailed examination of the constitution of the rock would prove of value.

A specimen taken from the base of this near to its junction with the Silurian, was submitted to Mr. Philip Holland, F.I.C., who analysed it as a whole, including contained sand and rock fragments, with the following result:—

$Si\ O_2$	54·58
$Al_2\ O_3$	6·91
$Fe_2\ O_3$	2·84
$Fe\ O$	1·58
$Ti\ O_2$	0·84
$Mn\ O$	0·39
$Ca\ SO_4$	0·39
$Ca\ CO_3$	15·56
$Mg\ CO_3$	11·49
$Mg\ O$	1·42
$K_2\ O$	1·40
$Na_2\ O$	0·95
Contained water	2·01
	99·86

Total CO_2 found = 12·865 per cent.
Specific gravity of the crushed rock 2·772.

It is thus seen that the cement holding the sand and fragments together is a Magnesian Limestone, consti-

tuting 27·05 per cent. of the rock. It is this that makes the basement-breccia so tough and so firmly-cemented to the highly-inclined Silurian laminated shales, below which it has, to a certain extent, penetrated so as to render it possible to get junction specimens showing Silurian and Old Red together, though separated in time by perhaps millions of years.

Another portion of this breccia was examined in detail by separating some of the included rocks and analysing them, from which it appears that in some cases the cement has penetrated the included rock.

Mr. Holland says that he separated two included fragments of sandstone from the matrix, one (A) of a greenish hue, the other (B) somewhat darker. A weighed amount of each treated with hydrochloric acid gave the following results on analysis:—

	A.	B.
Sand and Silica	79 15	90·10
$Ca\ CO_3$	9·14	1·25
$Mg\ CO_3$	7·83	1·29
$Fe_2\ O_3 + Al_2\ O_3$	3·11	4·60
Mn O combined water, matter not determined	0·77	2·76
	100·00	100·00

Small drusy cavities were visible with a lens on the various parts of the conglomerate from which with a needle were obtained crystals of calcite. Dotted over the specimens too were minute crevices filled with a white amorphous powder that did not effervesce, and on addition of H.Cl. did not dissolve in that reagent. Further examined it gave reactions for silicic acid and alumina, and Mr. Holland puts it down as Kaolin.

In the various papers on the subject I have referred to I have failed to notice any reference to this cement in the basement breccia. It appears to me to be a

chemical deposit akin to those cemented masses of gravel often found in the drift, where it is largely composed of limestone pebbles, but in this case the cement must have had an extraneous origin, and it is an interesting speculation whether the lixiviation of the volcanic rocks, such as those of which analyses have been given may not have yielded the lime and magnesia.

CARBONIFEROUS.

The Upper Old Red Sandstone passes up into the Lower Carboniferous Sandstones and Shales, and the gradation may be seen about a mile west of Greenheugh Point near Cockburnspath. These latter strata are also well seen in the valley of the Blackadder stretching along the southern edge of the map—a very beautiful vale.

These are succeeded by the Calciferous Sandstones, equivalents of the Lower Limestone Shales of England, the base of which may be seen in the Whiteadder at Preston Bridge. These lower beds consist of white and reddish sandstones with partings of clay and shale, and contain fragments of calamites and fern stems; they pass up into a series of sandy shales of various shades of green, grey, blue, and lilac. Succeeding these beds are a series of white and grey sandstones separated by greenish and reddish marly shales. These can be well seen on the shore at Burnmouth when the tide is out, running in parallel lines across the bay, the succeeding white sandstones with intervening beds of shale forming ridges as regular as if ruled by artificial means.

These beds, continuing south eastward, appear in the cliff at Ross in highly inclined vertical and even reversed positions, and appear very prominent when the sun is on them by reason of the denudation of the soft red and grey shales which takes place between them, leaving the

harder beds of sandstone projecting in vertical ridges up the face of the cliff. The high inclination of these beds appears to be due to their proximity to the great fault previously mentioned as extending from Burnmouth to Berwick.

True it is that as we travel southward along the coast the beds become nearly horizontal, but I could not find the locality where the change of inclination takes place.

At the headland, south of the Maiden Rock, the structure of some of the sandstone beds is well exposed by denudation, and the rocks assume strange forms. An examination shows that the exposed surfaces of the beds, which are tilted at a high angle, are curiously weathered out in irregular cracks, the intervening shales having been carried away by the denudation of the sea, leaving the surfaces of the beds of harder rock well exposed to view.

At Lamberton Beach the highly inclined strata which extend eastward from Burnmouth are overlaid with a band of limestone full of *Lithostrotion* and *Productus giganteus*, representing the beginning of the Carboniferous Limestone group. Following this bed is a series of thick red sandstones with thin coal seams at the base. These beds become horizontal towards Marshall Meadows Bay, where the bright red sandstones may be seen reposing upon beds of shale and limestone full of carboniferous fossils.

At a former time some thin coal seams that occur here were worked, but had to be abandoned, as they did not pay the cost of extraction. The thickness and horizontality of the beds at this bay quite change the character of the coast scenery. Some big cubical slips of rocks have taken place, and the railway which formerly ran in a cutting near the edge of the cliff had to be

diverted more inland. The deserted railway cutting, now all grass-grown, looks quite singular with its road bridge spanning a railless and trainless track. This amphitheatrical bay is approached by an artificial tunnel which, commencing in a depression inland of the edge of the cliff, debouches in the Bay on the top of the talus slope of the cliffs.

As regards scenic effect there is nothing in these carboniferous cliffs to remind one familiar with the grey Yorkshire and black Lancashire carboniferous, that they are equivalent rocks. It is only when we get to the shore at Spital, south of Berwick, that we readily recognise in the Upper Limestone Shales and Sandstones, the well known sombre tints of our carboniferous formations.

CARBONIFEROUS AND POST CARBONIFEROUS IGNEOUS ROCKS.

Dykes of greenstone are to be seen on the shore at Burnmouth, and at Cateairn Bushes; a greenstone dyke crosses the great fault between the Silurian and Carboniferous without disturbance, showing that it is post Carboniferous. Geikie considers "it is quite possible that "some of the dykes and masses in the Upper Old Red " Sandstone may be of earlier date than the Carboniferous " system," and points to Dunse in the left hand corner of the map as a focus of volcanic action; at the "close of " the Old Red Sandstone period, as shown by the ash of the " Whiteadder and the Hardens Valley." The greenstone dykes seen in the Silurian cliffs, west of Burnmouth, are quite distinct from the felstone dykes already described, and are probably of post-carboniferous age.

GLACIAL.

Striæ.—There are but few signs of glacial grooving and polishing of the rocks *in situ,* but at St. Abbs Head, in the grounds enclosed by the lighthouse, we observed

near to the drive, which is cut through the purple porphyrite, several polished surfaces, the direction of the striæ thereon varying from about N. 45° W. to N. 55° W., but they were difficult of observation, and from the rough contours of the felstone rock only limited patches and bosses had been affected.

Drift.—The Glacial drift is not of a very interesting character, consisting of sand, gravel, and clay, mostly to be found in the glens. It is apparently barren of organisms, and contains so far as I could judge no real erratics, only rocks that might have been derived from any of those described in this paper. The drift is to be seen in the railway cutting at Burnmouth, in the quarry below Catch-a-penny, and other quarry openings, and at the cliff below the Fort at Eyemouth Bay.*

In the glen above Ross Village, Burnmouth, there is a very fine red loamy drift, containing a few striated stones.

At the Tile works now disused, near the Ale water, just S.E. of Ale Mill, occurs a clay very like the glacial low-level brick clay of Liverpool. I observed one deeply scored boulder of purple greywacke, and minor striæ on other stones.

There was a great variety of igneous rocks in the clay; ashes, porphyrites, and greenstones. The level of this clay is about 200 feet above the sea.

I append Mr. Joseph Wright's report upon these drifts, which he was kind enough to examine for me :—

No. 1.--Clay from Tile Works, near Ale Mill, Eyton, weight 13 oz., after washing 3 oz. fine, 1 oz. coarse. Most of the stones angular. *No foraminifera.*

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*Geikie mentions 75 feet of clay and shingle at the N.W. end of valley at the back of St. Abbs Head. This I had no opportunity of seeing.

No. 2.—Clayey drift, top of quarry, Catch-a-penny, taken from the base near bed rock. Weight 13 oz., after washing 3 oz. fine, 3 oz. coarse. Most of the stones angular. Floatings accidentally lost.

No. 3.—Very fine red loamy sand (drift with drift stones) from side of glen above Ross Village, Burnmouth. Weight 2½ lbs., after washing 1oz. fine, ½ oz. coarse, stones rounded. *No foraminifera.*

DYNAMICAL REFLECTIONS.

In "The Scenery of Scotland viewed in connection with its Physical Geology," Sir Archd. Geikie has shown that the Southern Uplands—a rolling platform of moorland of which this description only touches the eastern margin—has been carved out of Lower Palæozoic rocks, which run in parallel folds, having a N.E. and S.W. strike across the south of Scotland from sea to sea. The highest point of these rocks is in Merrick, 2,764 feet above the sea, the next prominent heights being Rinns of Kells (2,668 ft.), Cairnsmore of Carsphairn (2,612 ft.), and Cairnsmore of Fleet (2,331 ft.), all three of granite, protruded into Palæozoics, which it has considerably altered.

These granite bosses have doubtless been originally deeply buried in the greywackes, which have from their less resistant action to atmospheric agencies been since denuded away. What the total thickness of these lower Palæozoic shales is, it would be difficult to ascertain. Geikie estimates that there are probably not less than 4,000 feet of grits and shales in the synclinal trough between Siccar Point and Burnmouth. That the thickness must have been originally very great before plication we know from the enormous denudation it is evident these highly inclined beds have since undergone, as well as from the known relations between thickness of sediment and the amount of compression and upheaval that takes place. Furthermore, Dr. Lapworth has shown by conclusive evidence that in the S.W. of Scotland, at Girvan, there is a regular sequence of lower Palæozoic rocks, more or less

fossiliferous, estimated by him to be of a collective thickness of 7,000 ft., and below these again come the Ballantrae rocks of unascertained age. Taking as a base line of reference, the strikingly individualised Benan Conglomerate, Dr. Lapworth, step by step, traced the relations of the associated underlying and overlying beds, though displaced and complicated by faulting, in a masterly manner. The process of reasoning and observation by which he attained his results, which are told in full in his paper "On the Girvan Succession," constitute in themselves a good study in field geology.

There is every reason to believe that these folded Ordovicians and Silurians pass under the Carboniferous rocks which occupy the midland valley between the Highlands and the Southern Uplands. These much folded beds are oft repeated strata of sandstones, greywackes, or shales of no great thickness, that naturally give to lateral pressure by folding. In Wales where the rocks are of a more massive cast, they have usually yielded by horizontal compression and vertical extension, hence the prevalence of cleavage in Wales, and the absence of it in the greywacke rocks of the south of Scotland.

The vertical attitude of the beds is also more favourable for the insidious attacks of the forces of denudation. It seems probable that the plication of the Ordovician began before the deposition of the Silurian, which lies upon it unconformably, as is also more decisively the case in South Wales.

From the general folding of the strata it is difficult to approximately estimate the vertical amount of rock that has been removed. The larger part of the denudation has doubtless taken place, firstly, before the deposit of the Silurian, and secondly, before that of the Lower Old

Red, which appears to lie in conformable sequence upon the Silurian.

It is difficult to allot to each period its relative amount of denudation, as the lower rocks have been affected in all the preceding periods, as they have been since the Carboniferous up to the present time. Geikie has pointed out that the lines of water partings and the valley system throw considerable light upon the physical history of the region.

They are both mostly independent of the structure of the country they traverse, showing that their direction has been determined under other conditions when the platform of hills was covered with the later formations of the Old Red and Carboniferous, or the Carboniferous alone, which is found in the Sanquhar Coal field resting directly upon the upturned edges of the Silurian.

In connexion with the geology of the Berwickshire coast, Sir A. Geikie's "Scenery of Scotland" may be advantageously perused. He gives a very graphic picture of the characteristics of the Southern Uplands, with the sentiments of which I find myself in full accord. With the physical explanations I am also in general agreement, as is seen from my previous remarks. There is one point, if I may be allowed to criticise, in which I think he does not sufficiently differentiate between two distinct phenomena. It is between the faulting and folding. Doubtless the overthrust and fault planes of the Highlands are due to the same cause as folding, namely, lateral compression, but such faulting as occurs between Stonehaven and the Firth of Clyde, and Girvan and the Firth of Forth by which the whole midland coal field of Scotland is let down,*

*In a clever paper by Peter Macnair and James Reid (Geo. Mag. March, 1896), "On the physical conditions under which the Old Red Sandstone of Scotland was deposited," published since this paper was written, they say that to the south of the line of the Stonehaven and Firth of Clyde fault, there are "massive beds of Old Red Sand-

is another type of disturbance, as I have shown in my "Origin of Mountain Ranges." This type of faulting is due to subsidence, and is accompanied by shearing. It is as I have shown due to contraction of the underlying beds and crust of the earth, and *cuts through and is consequently subsequent to the plications.* The same remarks apply to the fault described on the Berwickshire coast, letting down the Carboniferous against the Lower Silurian. Perhaps we cannot well have a better illustration of my meaning than the diagram, Section No. 1, across Sutherlandshire, at the top of the Geological Map of Scotland, attached to the last edition of the "Scenery of Scotland." In this section a series of *reversed faults,* or minor thrust planes, are shown, by which strata are pushed over each other and sandwiched together in an unnatural order of succession. At the same time to the left are shown *three normal faults,* which have let down the strata so sandwiched together and dissever two of the major thrust planes. A more convincing proof of the normal faults being *subsequent* to the lateral pressure producing the reversed faults and thrust planes could scarcely be desired. It is also evident that the normal faults *must* be due to a differently applied force to that producing the lateral compression and thrust planes. It is none other than vertical shearing by gravitation, a

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"stone, dipping at high angles to the S.E., and estimated to be about "20,000 feet thick, about four times the present height of Ben "Muich Dhui." To the north of the line of fault, resting upon the crystalline schists are to be found "patches of the basal Con-"glomerates of the lower Old Red Sandstone still occupying its "normal and unaltered position, so that if the effect of the great "fault were undone and the whole Old Red Sandstone deposits of "Strathmore were upraised to their original position, they would "overlook the Highland area to an altitude of four times its present "elevation." Can anything emphasise more than this the constant relations that exist between great sedimentation and such movements, or show that the extent of the throw of a normal fault bears a distinct relation to the thickness of the sedimentary beds so severed and thrown down."

method by which the earth's crust adapts itself to shrinkage, which is not only linear but voluminal. "Nature abhors a vacuum," therefore the crust is refitted together by normal faulting. I think it necessary to make these observations, because it is of the utmost importance to discriminate between two different dynamical phenomena, which are really the complement of one another, namely: those due to *lateral pressure*, which produces the plications and packs the strata together tightly, and those due to *contraction*, which produces rupture by tension and shearing by downthrow.*

These principles are quite independent of any views which may be held as to the *cause* of the compression or of the shrinkage, but, as I have attempted to show, looked at dispassionately, throw great light upon the probable agencies at work in so breaking up and recomposing the crust of the earth. There is a still further inference which explains the principle called attention to by the

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*Playfair observes with considerable acumen (Illustrations of the Huttonian Theory, pp. 62 63) "The highly inclined positions and "the manifold inflections of the strata are not the only proofs of the "disturbance they have suffered, and of the violence with which they "have been forced up from their original plane;" he then goes on to speak of the "slips or shifts that so often perplex the miner in his "subterraneau journey, and which change it and all those lines and "bearings that had hitherto directed his course. . . . . They "are however of a date posterior to that of which the waving and "undulated form of the strata were acquired, as they do not carry "with them any marks of the softness of the rock, but many of "its complete induration." Becker (Gold Fields of the Southern Appalachians, 16th Annual Report of U.S. Geological Survey, part ii., p. 23, 1895) observes "The opening of the fissures now occupied "by ore, or which afforded the ore-bearing solutions access to the "spaces now occupied by impregnations, took place later than the "movements which rendered the country schistose," and he goes on to show that the opening of these vein fissures is due as a rues to Normal faulting, and recognises that it must arise from a *reversal* of the general tendency to overthrust movements. Why he should callthis reversal "temporary" is not so clear. It is, as we have seen, the effect of that contraction which *always* follows the cessation of lateral pressure which has produced the mountain range.

Rev. F. F. Grensted.* Great Normal faults that traverse plicated strata often follow the axis of the folds, as if these constituted lines weakness, as instance the Stonehaven and Firth of Clyde fault, and the fracture determining that remarkable valley of the Highlands between Loch Linnhe and the Moray Firth, called the Great Glen. In the explanation of sheet 7, Ayrshire (south western district) it is stated (p. 13) "that all the large faults in "that area run from S.W. to N.E., which is the prevalent "direction of the greater dislocations throughout the "southern half of Scotland, as well as the chief line "of strike of the geological formations throughout Great "Britain." Prof. Lapworth in his paper on the Girvan Succession (Q.J.G.S.) vol. xxxviii. p. 545 (1882) also called attention to two gigantic faults, long recognised as affecting the stratified rocks of the district. "The "northern or *Craighead* fault has been proved for a distance "of 21 miles; while the southern or Bargany fault is in "all probability of equal longitudinal extent. The general "direction of these faults is from N.E. to S.W., in other "words their course coincides with the general strike of the "Lower Palæozoic rocks of the region. They are in reality, "*strike faults*, whose existence would long have remained "unsuspected were it not for the fact that with respect to "the overlying Carboniferous strata they are more or less "*dip faults*, abruptly truncating the gently inclined Carboniferous beds and flinging them down along two "comparatively straight lines crossing the perpendicular "or highly convoluted Lower Palæozoic rocks below."

Further examination of this interesting region would doubtless yield important results, but I trust that even

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* Contributions to the Dynamical History of the Craven Highlands. Proc. of the L'pool Geo. Soc., Session 1895 6.

the partial attention I have been able to give to the problems of the earth in this classical district are not altogether without value.

NOTES ON ANALYSES OF PERMIAN AND TRIASSIC ROCKS FROM THE NEIGHBOURHOOD OF LIVERPOOL.

By P. Holland, F.C.S., F.I.C., and E. Dickson, F.G.S.

(*Read 14th April, 1896.*)

The Proceedings of this Society record but few analyses of the sandstone rocks of this neighbourhood; a paper by Dr. Campbell Brown, and two by Mr. Tate, comprising, so far as we know, the only information of a chemical kind with regard to these rocks.

By the kindness of our Hon. Secretary we have been supplied with specimens of rock from several localities in the district. The collection includes a marl, the composition of which it will be interesting to compare with that of a marl of Permian age underlying magnesian limestone at Skillaw Clough. Our chief object in the examination has been (1) to investigate the chemical and microscopical characters of the rocks and marls, and in the case of specimens (as those from Storeton) in which the sandstone and marl are juxtaposed, to ascertain if the marl has an origin distinct from the sandstone, or if there be any evidence that it is a decomposition product of the latter; (2) to learn the nature and the amount of the matter that cements together the grains of sand, as we found that on testing these rocks with acid they gave no reaction for carbonates, whilst their somewhat pale colour seemed to

preclude iron oxide as the cementing agent. We may just remark that the Storeton sandstone, and also that from Poulton, contained traces of barium sulphate. By appropriate treatment of 8 grammes of the sandstone a solution was obtained in which barium could just be detected on addition of dilute sulphuric acid. The chemical reaction for barium was, however, at once confirmed on appeal to the spectroscope. Copper could not be detected, but lithium was. The latter will proceed possibly from the micas, as we found to be the case in a granite from the Isle of Man, of which the mica gave a distinct spectral reaction for lithium.

The presence of barium is seldom recorded in the published analyses of sandstones, though Dr. Frank Clowes has drawn attention to barium sulphate as a cementing material in the new red sandstone beds near Nottingham (Chemical News of October 16th, 1885 ; also Abstracts, Journal of Chemical Society for 1886).

When comparing slides of the sandstones and marls under the same magnification, there was a noticeable difference in size of the sand grains of the two deposits. In the marls the fragmentary particles of every kind are exceedingly small; a few rounded sand grains occur, but the bulk of the marl consists of "rock flour" with micaceous ferruginous clay. The angular particles of "rock flour" so largely composing the marls would, when the sandstone is juxtaposed to the marl, as at Storeton, almost suggest a sandstone origin for the marl. Slides of several marls were examined, when the same general characteristics, viz., the angularity and fine texture of the detrital silica, were observed to be distinguishing features of the deposits. In the Storeton marl the few rounded grains of quartz resemble in shape and colour those of the overlying sandstone. This marl, of a

chocolate colour and easily crushed, is devoid of all calcareous matter, and will owe the cohesion it has to the plastic nature of the alumino-ferric clay. Full analyses were made of this Triassic marl and of the Permian marl from Skillaw Clough; both are given for purpcses of comparison. The Skillaw marl lies below magnesian limestone—as will be seen on reference to the plan in a paper on this section read last session. The lime and magnesia carbonates in the marl will probably have come from the limestone.

With these few preliminary observations we will now give a list of the specimens and their analyses in detail:—

I. A light grey sandstone, somewhat friable, from Storeton Quarry.

II. From a bed of marl underlying I.

III. From a thin bed of light grey very friable sandstone of finer texture than I., occurring in the marl bed, and quite free from adherent red marl.

IV. A light grey sandstone immediately below the marl, of same texture as I., but harder.

V. Joint filling from West Kirby, Cheshire, Upper Bunter.

VI. Keuper sandstone, Poulton.

VII. Permian marl, Skillaw Clough, near Parbold, Lancashire.

The analyses were made on uniform finely powdered samples previously dried at 100° C. The combined water was estimated directly, and not by the "loss on ignition" method.

The Sp. Gr. determinations were made on the dry sample by the Sp. Gr. bottle.

	I. Sandstone from Storeton.	II. Marl below I.	III. Sandstone in II.	IV. Sandstone below II.	V. Joint Filling, Upper Bunter, West Kirby.	VI. Keuper Sandstone, Poulton.	VII. Permian Marl. Skillaw Clough.
$Si\,O_2$	93·72	53·18	87·68	91·08	95·52	91·58	48·60
$Fe_2\,O_3$		5·53					4·85
$Fe\,O$		nil.					nil.
$Al_2\,O_3$	3·70*	24·99	7·51*	4·75*	2·62*	4·94§	13·73
$Mn\,O$		0·28	trace.				0·41
$Ti\,O_2$	0·22	1·09	0·37	0·26		0·07	0·81
$Ca\,O$		trace.					8·26
$Mg\,O$	0·13	1·97	0·18	0·18	trace.	0·05	5·33
$C\,O_2$							11·15
$S\,O_3$							0·02
$P_2\,O_5$		nil.					nil.
$K_2\,O$	1·51	7·13	2·42	2·03	1·27	2·62	3·14
$Na_2\,O$	0·25	0·39	0·30	0·42	0·25	0·32	0·59
Combined Water...	0·55	5·43	1·50	1·18	0·28	0·48	3·40
	100·08	99·99	99·96	99·90	99·94	100·05	100·29
Sp. Gr.	2·638	2·807	2·619	2·616	2·644	2·633	2·749

The Sp. Gr. is higher in the marls than in the sandstones, owing to oxide of iron.

* Chiefly $Al_2\,O_3$ slightly coloured with $Fe_2\,O_3$

§ $Al_2\,O_3$ more coloured with $Fe_2\,O_3$ than in I., III., IV., and V.

The sandstones it will be seen are free from lime salts, a not uncommon cement in many such formations, and since the total of oxides of iron and alumina falls below eight per cent. and is not all clay, some material other than lime or clay must cause the cohesion of the sand grains. Now it was observed on carefully crushing the sandstones, employing a minimum of pressure, that the fine mud, removable from the crushings by systematic washing with water, was for the most part fragmental quartz with mica and particles of felspar. There appeared to be but little ferruginous clay. The composition of the cement presenting points of interest, we took for comparison equal weights of the respective rocks, and after crushing and sifting them through wire gauze, washed the portions with distilled water. The washing was continued in every case until the water had but a slight turbidity. The residual sand was collected, dried at 120° C. and weighed. The washings containing the fine stuff were evaporated in a counter-poised dish, and the residue left in the dish was dried as the sand, and weighed. These operations gave two fractions for each sandstone, A the larger consisting of coarse sand, and B the smaller of fine fragmental silica and finer sand, together with clay and particles of mica.

The plan with each rock was to take 10 grammes and stir it about with water in a beaker, using a glass rod shod with rubber tubing. The cement by this means was readily detached from the rounded grains of sand, and could be decanted with the water and separately collected ready for the dish. In order that the plan of operating should, as far as possible, be identical for each sandstone, we took a like total volume of water for every 10 grammes of rock and added it to the rock in

equal measured portions at each stage of the washing. The following figures were thus obtained for the five sandstones:—

	I.	III.		IV.	V.	VI.
Fraction A......	95 23	83·84	83·60	92·77	87·95	95·03
,, B......	4.77	17·16	16·40	7·23	12·05	4·97

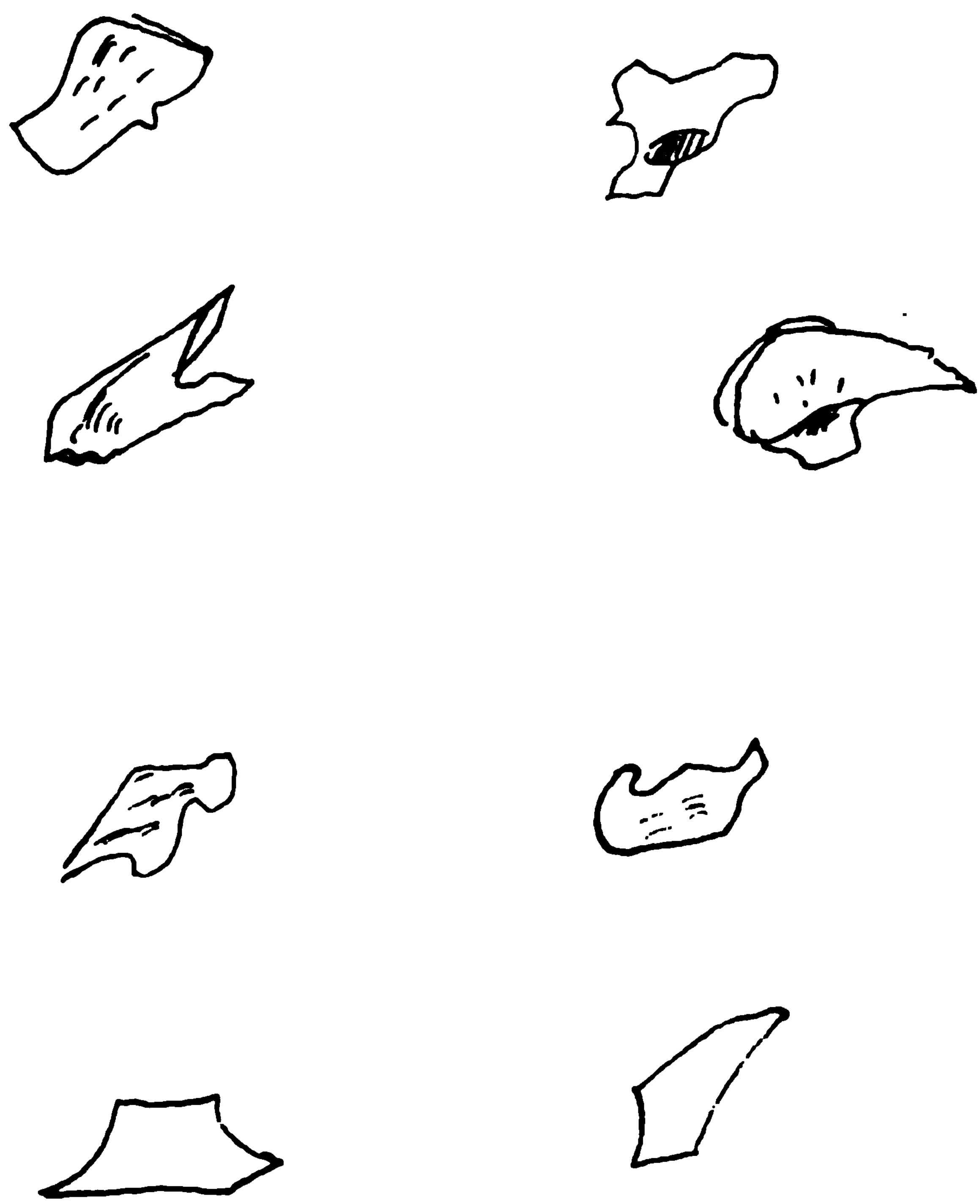
As No. III., "friable sandstone in marl bed," gave a much more milky washing than did the other specimens, the operation was repeated as a check on the figures first obtained, since the milkiness would seem to indicate clay. When fraction B, the fragmental silica and clay, had been weighed it was without removal from the dish, heated with strong hydrochloric acid, and the usual operations were followed for separating iron and alumina from a siliceous residue. Treating B so, gave also two fractions, C, the detrital silica, felspar and mica; and D, the acid liquid containing the oxide of iron and alumina belonging to the clay. These fractions after suitable treatment were weighed. The combined water of the clay in B was not estimated, nor was the filtrate from the alumina further examined, except so far as to test it for magnesia, which was found in all cases, as was also manganous oxide.

PERCENTAGE COMPOSITION OF FRACTION B.

Fine Silica	I.	III.	IV.	V.	VI.
C.	90 08	88·93	89·25	97·32	82·65
Alumina and Oxide of Iron.					
D.	4·11	3·58	4 20	1·26	9·81
Matter not estimated and loss	5·81	7 49	6·55	1·42	7·54
	100·00	100 00	100 00	100·00	100·00

It will be seen from these numbers that fraction B is chiefly silica.

It is instructive in the case of No. III. to observe that the light coloured cement washed from it, though



FLAKES AND SPLINTERS OF SILICA.

To illustrate Messrs Holland and Dickson's Paper.

Proc. Liverpool Geological Society, vol. vii., pt. 4.

amounting to 17 per cent. of the sandstone, is, as a matter of fact, not so aluminous as the cement of No I., which yielded but 4·77 per cent. for the B fraction.

The microscope shows the silica of No. III. to be of finer grain than is the case in the other specimens. This fineness of grain will tend to a larger amount appearing in the B fraction than would be the case were the cement coarser and less easily washed out. Whatever may be the value of the method just described, it will at any rate prove of service when comparing together sandstones from different areas as to the amount and nature of the cement they respectively contain. The enquiry so far has shown that in these specimens, as in many other sandstones of continental origin, the grains of sand are not bound together by calcite, nor is their cohesion due to any considerable amount of ferruginous clay, though the figures for No. VI. show more matter of a clayey nature in this rock than in the other specimens. A glance at the figure for the potash in the analysis of No. VI. indicative of the felspar will explain the larger amount of clay. Kaolinized felspar, the source of the clay, is well represented in this sandstone, from which the mineral could be picked out and identified.

Turning our attention next to fraction C, the residue of the HCl treatment of fraction B of the original sandstone, we found it almost entirely made up of fragmental silica, together with felspar and flakes of mica.

The siliceous cement from all the sandstones under a ½ in. objective and binocular vision is seen to consist of flakes and splinters, many having curved or hollowed outlines; some have rounded incisions. We give a few of the figures observed showing curvilinear outline. The forms of the splinters would clearly suggest a moulding of this interstitial silica round the grains of

sand. This may likely be silica of secondary growth on the sand grain and differing in physical properties, as such deposited silica may conceivably differ from that of the sand grains, would split off them in lines of least resistance when the sandstone was crushed and washed in the manner described.

The Poulton Keuper largely consists of twinned crystals of quartz with mineral inclusions. On the faces of some crystals there were deposits of apparently non-crystalline silica. *Dr. Irving, in a paper "On Organic Matter as a Geological Agent," refers to the action of humic acids as agents in the separation of dissolved silica. It would appear that silica so set free will attach itself to already existing quartz grains. That all ammoniacal salts will separate silica from its soluble alkaline combinations, is an established fact. Humic acid—a product of decay of vegetal remains, which may be and often are nitrogenous—might appear as ammonium humate and cause such separation, though the acid alone would do so. It is not possible to define the way Nature decomposes the felspars and other alkali-bearing minerals so as to make use of their constituents, that is to say to define the steps by which she proceeds. When, however, the felspars become weathered, then will the potassium silicate in them become dissolved in water, and the silica be ready for separation and precipitation by humic acid or other effective agent. Our own experiments on the separation of silica from weak solutions of potassium silicate have been made with water expressed from peat, but they are not yet complete. Though humic and allied organic acids will be largely effective in separating silica, the geologist need not rely on them alone, for ammonium

* Report of the Geologists' Association, vol. xii.

nitrate will do equally well, and this salt has been found in the rain water at Basle to the extent of 20·1 parts per million along with nitric acid.* The amount of ammonium nitrate in the rain at Basle may have been exceptional, still there is abundant evidence of the presence of this salt in the cloud water and dew of various parts of Europe. The gaseous emanations of our planet at volcanic vents, as well as those proceeding from the decay of the off-scourings of its inhabitants, are dissolved in aqueous vapour and return to the soil in rain, and thus it is that rain and dew are so fertilising to the soil, and at the same time so effective in rock erosion.

In the sandstones from Storeton Quarry the consolidation of the grains of sand would appear to be caused either by infiltration and subsequent precipitation of dissolved silica, or by the close packing of the grains with "rock flour." Both causes may obviously have operated at the same time. The close packing by pressure alone, as a sufficient means to induce consolidation, finds a parallel in the consolidation of powdered clay by pressure, as in the manufacture of the Minton tile.

A comparison of the analyses of the Storeton sandstone with that of the underlying marl would suggest a relationship between the two deposits, for we find in each, rounded sand grains, flakes of quartz and mica, and an absence of calcareous matter. Contrasting the figures for the Storeton sandstone and marl, the silica of the latter will be found to be somewhat more than half that in the sandstone, whilst the iron oxide and alumina are nearly eight times as much.

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* Air and Rain. The Beginnings of a Chemical Climatology. R. Angus Smith, F.R.S.

One is tempted to enquire, are not both deposits the immediate derivation of the same parent primitive rock, and may not the decomposition of the rock have taken place under conditions favourable to the non-dispersal of both residuals, viz., the sand and the marl? Sandstone No. I. "over marl," and No. IV., that "below marl," are almost alike in composition. The latter sandstone it is true has somewhat less silica than No. I., but contains one per cent. more alumina, due to more felspar, as the figures for the alkalies show. Seeking to trace a relationship between sandstones III. and IV., we might for such purpose perhaps regard the deficiency in silica in III. to have been replaced by alumina; so that, taking the difference between the figures for the alumina in III. and IV., and adding it to the silica of III., we should bring the analysis of the latter more into line with that of IV., for the silica would then be 90·44, instead of 87·68 per cent. as it now is, and the alumina the same in both rocks.

A SKETCH OF THE PROCESS OF METAMORPHISM IN THE MALVERN CRYSTALLINES.

By C. Callaway, D.Sc., M.A., F.G.S.

(*Read 14th April, 1896.*)

In view of the recent visit of the Liverpool Geological Society to the Malvern District, it may be of interest to the members for me to give a brief account of a few of the phenomena which they then studied under my guidance. The sedimentary rocks, from the basal Cambrian up to the Trias, are too well known to Geologists to need description here. The volcanic masses east of the Herefordshire Beacon come next below the Cambrian in the Malvern area, but the limits of this paper prevent their description. I therefore propose to confine myself to the ancient crystallines which form the axis of the Malvern range, and to offer a short explanation of the process by which the massive plutonic rocks have been metamorphosed into gneisses. I discharge myself of this task with the greater pleasure because that, in doing so, I am complying with a request made to me some time since by your President, my friend Mr. T. Mellard Reade.

I may premise that the theory which I here advocate is the result of some six or seven years of detailed work in the field, supplemented by the study of several hundreds of microscopic slides. My conclusions have been set forth in a series of three papers * published in the Quarterly Journal of the Geological Society, and they have been further illustrated and defended before the British Association,† and in the pages of the Geological Magazine.‡ In this paper I shall merely summarise

* Quart. Journ. Geol. Soc., 1887, p. 525; 1889, p. 475; 1893, p. 398.
† Manchester, 1887; Bath, 1888.
‡ P. 545, 1892; p. 535. 1893; p. 217, 1894; p. 120, 1895.

my results, and indicate the line of evidence which leads up to them.

1.—The Problem Stated.

All previous writers on the Malvern district have noticed that the crystalline axis of the hills is largely composed of diorites and granites. They also recognised that these massives graduated into rocks which, though still crystalline, displayed a parallel structure, as if they had been deposited in beds. Laminæ of quartz, felspar, mica, hornblende, and other minerals, alternate with each other, sometimes with great regularity, sometimes in lenticular flakes. Murchison* inferred from these facts that the gneisses and schists were metamorphosed Cambrian sediments, into which granite-veins and diorite-dykes had been intruded. †Dr. Holl held a similar view, but he supposed that the gneisses were of Laurentian age, and he believed that, by a process of extreme metamorphism, they had been sometimes converted into such rocks as diorite; though he appears to have thought that some of the diorites were intrusive.

The conclusions to which I have been led simply reverse those of Murchison and Holl. I hold that the gneisses have been formed out of the igneous rocks, not the igneous rocks out of the gneisses. All the crystallines of Malvern were originally massive and amorphous. By a process of crushing and shearing, accompanied by the evolution of heat and the generation of intense chemical energy, a parallel structure has been here and there produced, new minerals have been formed, and reconstruction on a large scale has been effected. A few details of this theory are here submitted.

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* Siluria, p. 93.

† Quart. Journ. Geol. Soc., 1865, p. 72.

2.—The Materials to be Metamorphosed.

All the schistose and gneissic rocks of Malvern are formed out of two or three varieties of diorite, an epidiorite, a granite, and a felsite. The most abundant of the diorites (and it is probably the oldest rock in the area) is a rock of a dark green colour and of a medium texture. It is well seen* in the large quarry on the northern side of the Hollybush Pass, in the small quarry at the Wych, in the quarries at West Malvern, and at North Malvern. It is chiefly composed of green hornblende and whitish plagioclase felspars. Into this rock there is often intruded a coarse granitoid diorite (called by Mr. Rutley a "hornblende gabbro") of similar mineral constituents, and of almost identical chemical composition. It is easily differentiated by its coarser texture and grayish colour. The granite, which is a binary compound of quartz and potash felspar, has penetrated the diorites in veins and dykes, and it often occurs in conspicuous masses hundreds of yards in diameter. It was seen at all the localites visited. A compact purple felsite is also intruded into the diorites, and was studied at the south-eastern end of Raggedstone Hill, where it is converted into mica-schist. In the same quarry was seen a schistose epidiorite, which is a metamorphosed dyke of dolerite. The Malvern Hills also probably contain some ordinary unaltered dykes of dolerite. The Malvern crystallines were therefore originally a complex of igneous rocks, formed at great depths, and intruded into each other in veins, dykes, and masses.

3.—The Process of Metamorphism.

After the rocks of the complex had consolidated—or the greater part of them—the whole mass was subjected

* I confine myself mainly to the localities visited by the Society at Easter.

to enormous pressures, acting for the most part along a north-east and south-west line, which caused the rock here and there to give way, and flow along planes at right angles to the direction of the compressing force. I say "flow"; but it will be easily understood that the flow of a solid differs materially from that of a liquid. The former yields to the pressure by fracturing; it can give way to the new stresses only by breaking into fragments, and these, as the crushing continues, are forced to shear and slide over each other. They take the form of lenticles, which are of every size, from the dimensions of a sofa cushion down to one tenth part of the thickness and area of a wafer. In coarse rocks the lenticles are much thicker in the middle than they are in the felsite and the finer diorites, where they are almost like uniform sheets, though of course they thin out towards their margin. Where these lenticles are of conspicuous magnitude, the rock becomes an augen-gneiss.*

The bands of rock within which shearing has taken place, I have called "shear-zones." These zones vary in breadth between a few lines or inches, and several yards or hundreds of yards. They very frequently strike obliquely across the axis of the hills, and their laminated structure was believed by previous observers to indicate deposition under water.

There will be no difficulty in understanding that all this crushing and shearing has been attended by great chemical changes. In the first stages, decomposition took place. Hornblende was broken up into calcite, chlorite, epidote, and iron-oxide; potash-felpar was converted into quartz and white mica, and soda-lime felspar was more or less replaced by calcite, quartz, and white

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* Pointed out to the Society, south of the Wych.

mica. Some of these minerals are ultimate products of the metamorphic process, and remain unchanged during its later stages; but where the pressure and shearing grew more intense, reconstruction on a large scale set in. Chlorite united with potash and iron-oxide to form black mica, felspars were extensively re-generated, disseminated iron-oxide assumed a crystalline form, and the crushed rock passed into a sound clear gneiss. This transformation is well illustrated by the section at the hamlet of White Leaf'd Oak. The crystalline rock immediately underlying the Hollybush Sandstone is a well-marked mica-gneiss, which passes into a laminated grit, which is but a crushed form of the coarse grey diorite. The Hollybush Sandstone (Lower Cambrian) is chiefly composed of bits of the underlying gneiss, which is thus shown to be of Archæan (Pre-Cambrian) age.

The mechanical forces operating in the metamorphism were partly converted into heat. This can be demonstrated by direct observation of microscopic slides. The fragments produced by the crushing are seen in a later stage of the schist-making to lose their angularity, and to be flattened out into minute lenticules. These are often cemented together to form larger lenticules. In the completed gneiss, the fragmental structure is often completely lost, but sometimes there remain a few crushed fragments of felspar to indicate, like an ill-cooked potato in Irish stew, the origin of the rock.

The crushed and sheared condition of the granites and diorites in the earlier stages of their change greatly facilitates the metamorphism. Heated waters percolate through the mass as through a sponge. The granite, partly decomposed, yields solutions of potash, which flow between fragments and along shear-planes, and help the chlorite to form black mica. Hence it is extremely

common to find shear-planes in gneiss coated with a film of this mica. Chlorite, epidote, iron-oxide, and other mineral substances, are also transferred from place to place, and give rise to new chemical combinations. The open condition of the crushed rock permits the frequent removal of bases. Thus, a rock which was originally highly basic may become acidic by the elimination of lime, magnesia, iron-oxide, alkalies, and even alumina. In this way quartzose gneisses may be formed out of diorite.

Banded gneisses may be produced by the interveining of igneous rocks, accompanied or followed by pressure. In the great quarries of North Malvern many examples of these injection-gneisses may be seen. Sometimes the gneiss consists of diorite interbanded with granite, sometimes of the dark green diorite with parallel veins of the grey variety.

It is interesting to notice how little of the original mineral composition of the rocks survives the process of metamorphism. In the change from granite to mica-gneiss, the felspar is transformed into quartz and mica, or is in part reconstructed as secondary felspar, sometimes of a different variety. The quartz of course cannot undergo any chemical change, but a large proportion of it has probably been re-crystallised. The diorite has been even more completely altered than the granite. Ordinarily, there are no traces of the original minerals in the resulting gneiss. The hornblende has been replaced by micas through the intermediary form of chlorite, with calcite, epidote, and quartz as subsidiary products. The felspar has been changed to white mica, quartz, and calcite, or it has been in part recrystallised in a secondary form. Perhaps the most striking feature

in the metamorphism is the secondary origin of the whole of the micas.

4.—The Products of the Metamorphism.

The chief kinds of gneiss have already been noticed. It only remains to summarise the results of the metamorphosing process. The gneisses may be divided into two main groups, as follows :—

A. Simple Gneisses, formed out of one kind of rock.

The following are the chief varieties :—

Muscovite-gneiss, formed from the granite.

Biotite-gneiss, resulting from the alteration of diorite.

Sericite-gneiss, produced from diorite.

Sericite-gneiss, from felsite.

Hornblende-gneiss, from diorite.

Actinolite-gneiss, from dolerite.

B. Injection Gneisses, formed by an injection of minerals or rocks into rocks. These are subdivided into—

(1) Gneisses of Primary Injection, or those which are produced by the injection of one rock into another. Hence we have the following kinds :—

Biotite-gneiss, formed from diorite veined with granite; or, if the veins have not caused the generation of much biotite, we have *granite-diorite gneiss*.

Duplex diorite-gneiss, or diorite with parallel veins of another diorite.

(*b*) Gneisses of Secondary Injection, or those resulting from the infiltration of mineral matter into a rock.

The best examples of this variety occur near the Wych, where a sheared granite has been infiltrated with chlorite and iron-oxide (from an adjacent diorite), which, with the addition of potash from the granite, have generated black mica. Thus the granite, *plus* injected chlorite and iron-oxide, has become a *biotite-gneiss*.

I fear that the extreme compression which the brevity of this paper has compelled has obscured my argument. If so, I can only refer those who are interested in the subject to my published communications and articles.

REPORT OF EASTER EXCURSION TO MALVERN, 1896.

The party left Liverpool on the afternoon of April 2nd, and were joined at Shrewsbury by Dr. Callaway, F.G.S., who had kindly consented to act as leader. Taking up their quarters at the Imperial Hotel, Malvern, they completed the arrangements for carrying out the programme.

April 3rd.—Drove to the western end of the Wych, and examined the old quarry on the southern side.

Here Granite was seen intruded into Diorite, and a complete series could be seen showing the conversion of these rocks into Gneiss. Near the principal planes of shearing much black mica was developed.

On the hill just above the quarry veins of Granite could be seen sheared into the Gneiss, giving the appearance of a gigantic Augen-Gneiss.

From the Wych, walked northwards along the western side of the ridge, examining the quarries by the way. Many veins of Dolerite were seen intruded into the metamorphic series, and occasionally there occurred cavities lined with fine tabular crystals of Barytes.

The circuit of the northern half of the hills was completed, and St. Anne's Well was visited on the homeward journey.

April 4th.—On the invitation of Mr. Dyke-Acland some of the members called at his house, and were shown, under the microscope, a very interesting series of slides of rocks from the Malverns. Later in the forenoon the party left by train for Stoke Edith.

On the way through the park adjoining Foley Hall pale grey thin bedded shales of Upper Ludlow age were examined, and yielded a good series of characteristic fossils.

The wooded ridge above the Hall forms an escarpment of the Aymestry Limestone. From the summit a grand view can be seen of the Woolhope anticlinal dome. Inside the ring-shaped escarpment of the Aymestry Limestone other concentric ridges are seen. They are caused by successive outcrops of limestones in the Wenlock and Woolhope Series. On descending the hill exposures of Lower Ludlow Beds were met with, and many fossils were obtained. At the bottom of the escarpment there are large quarries in the Wenlock Series. The rich harvest of fossils proved so attractive that the rest of the day was spent in collecting.

On the return journey another route was taken to the west of Stoke Edith, and several quarries in the Ludlow and Aymestry Beds were examined.

April 5th.—Drove to Eastnor, and thence to Rowick. A dyke of greenstone intruded into May Hill sandstone was observed in a small quarry by the roadside near Rowick. The party then walked across the fields to the White Leav'd Oak Quarry at the south end of Ragged Stone Hill. On the way black shales of Cambrian age were seen. No fossils were obtained, although they are known to exist there.

At the White Leav'd Oak there is a quarry giving good sections of the Hollybush Sandstone. Another quarry occurs higher up the hill, where it is again seen, this time resting on the older rocks. The east side of the quarry consists of Diorite and Granite, but towards the west these have been sheared into a perfect schist. The cleavage here is vertical, but where the Hollybush Sandstone overlaps, the top layers have been turned over uphill until nearly horizontal, as if by an upward movement of the sandstone.

The Malvernian rocks were followed along the east side of the hills as far as the Herefordshire Beacon. Some of the party elected to visit the camp on the summit of the Beacon, and on the way obtained specimens of the Uriconian lavas which flank the hill on its eastern side.

April 6th.—Left Malvern by train in the morning for Ledbury. Mr. G. H. Piper, F.G.S., met the party at the Station, and described the fine section of the passage beds at the base of the Old Red Sandstone exposed in the cutting between the Station and the Dog Hill Tunnel.

To the west are seen 332 feet of Old Red, which here takes the form of grey sandstones with red clays and marls. At the base the Ledbury grits come in, forming the upper division of the passage beds.

Then succeed red and purple shales, bands of red marls with Old Red Sandstone, Downton Sandstone, and the Silurians proper. The section is continued eastwards through the Upper Ludlow, Aymestry Limestone, and Lower Ludlow.

The passage beds are 390 feet in thickness, and have yielded a very interesting series of fossils, including Auchenaspis, Lingula, &c.

Under the guidance of Mr. Piper the party examined the sections, and afterwards were entertained at his house for lunch. The fine series of Palæozoic fossils collected by him were displayed. Mr. Piper was cordially thanked for his hospitality; and before the close of the excursion, an expression of thanks was conveyed to Dr. Callaway on behalf of the Society.

Several of the party remained at Wellington on their way home, and examined the Wrekin district.

HENRY C. BEASLEY.
J. LOMAS.

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